Habitat, Oceans and Fishery Management: Contributions through Environmental Sciences Research (1997 – 2002)

J.D. Pringle, L. Murray, and S.M. Verrin (Editors)

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by

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ACKNOWLEDGMENTS

A successful meeting requires enthusiastic participants, and that we had; thanks are extended to all the presenters and their respective staff who both assisted with the presentations and attended the meeting, and the support by their Section Heads Steve Macdonald, Robie Macdonald and Colin Levings. The meeting format required the active participation of staff from both Habitat and Enhancement and Oceans Branches (Directors Sue Farlinger and Dick Carson), from the Areas (Ron Kadowaki, Bruce Adkins, Colin Masson and John Lubar), from Fisheries Management (Wayne Saito), and from Aquaculture (Allison Webb), who all encouraged participation by their staff. Julie Henderson and Reet Dhillon provided their usual excellent administrative support to MEHS Division, and in particular for their behind-the-scenes efforts that ensured meeting success. Special thanks to Julie for recommending Laura Murray to "desk top publish" the proceedings and to Julie and Stacey Verrin for working with her on the booklet format.

DEDICATION

We dedicate this report to the memory of Ken F. Morton. Ken was a dedicated and productive Marine Environment and Habitat Science Division research biologist/limnologist, who made many contributions to the success of the Division including research on many of the sockeye populations and their rearing lakes in British Columbia. Ken was based at the Cultus Lake Laboratory throughout his career, beginning in 1979 with the International Pacific Salmon Fisheries Commission, and latterly from 1986 when he transferred to Fisheries & Oceans Canada. Ken passed away in May 2003 while carrying out research on Quesnel Lake. Ken had a strong dedication to fish habitat and the environment. He was well known for "getting the job done" even under difficult circumstances. Ken's wonderfully pleasant temperament, generous nature and dry sense of humour made him a pleasure to know and to work with.

ABSTRACT

Pringle, J.D., Murray, L., and Verrin, S.M. (Editors) 2005. Habitat, oceans and fishery management: Contributions through environmental sciences research (1997 – 2002). Can. Manuscr. Rep. Fish. Aquat. Sci. 2726: ix +104 p.

The Marine Environment and Habitat Sciences Division, Pacific Region, hosted a meeting in November 2002 that included their principal clients; oceans and habitat practitioners. The objective of the meeting was to discern if research carried out from 1997 through to and including 2002 was germane to the needs of the clients, was communicated in a timely manner and was delivered in a manner comprehensible to the clients. Research scientists and biologists within the Division gave a total of 23 presentations (extended abstracts of each presentation are provided in this report) on work that ranged from an assessment of the value to salmon of lake foreshore; through the impact of acid mind drainage on near-shore marine ecology; to the development of a science-based monitoring scheme, "Shorekeepers", in support of "citizen science". The bulk of the research was funded by the Department of Fisheries and Oceans' Environmental Sciences Strategic Research Fund or the Fund's various predecessors. The attending practitioners assessed the presentations and provided feedback to the presenters. For the most part the presentations were deemed comprehensible, and the "extended abstracts" written with the practitioner in mind. However, frequently scientific staff either failed to highlight the fact knowledge transfer had taken place or, that their work had been useful in the regulatory process, and /or in the development of Departmental policy. The compilation of work does show that these scientific researchers, during the study period, have been diligent in attempting to meet the research needs of the oceans and habitat practitioners.

106-00355/

RESUMÉ

Pringle, J.D., Murray, L., and Verrin, S.M. (Editors) 2005. Habitat, oceans and fishery management: Contributions through environmental sciences research (1997 – 2002). Can. Manuscr. Rep. Fish. Aquat. Sci. 2726: ix +104 p.

La division des sciences de l'environnement et des habitats marins de la Région du Pacifique a organisé en novembre 2002 une réunion à laquelle ont participé ses principaux clients, professionnels des océans et de l'habitat. L'objectif de la réunion était de déterminer si les études menées entre 1997 et 2002 répondaient aux besoins des clients et si leurs résultats étaient communiqués de manière opportune et compréhensible. Les chercheurs et les biologistes de la division ont donné en tout 23 présentations (un résumé détaillé de chaque présentation est donné dans le présent rapport) sur des travaux qui allaient de l'évaluation de la valeur des berges des lacs pour le saumon à l'élaboration d'un système de surveillance scientifique – les Gardiens du littoral – en soutien à la « science au service des citoyens », en passant par l'impact des effluents miniers acides sur les écosystèmes marins situés près du rivage. Le plus gros de la recherche a été financé par le fonds de recherche stratégique pour les sciences environnementales du ministère des Pêches et des Océans ou les divers prédécesseurs de ce fonds. Les professionnels présents ont écouté les présentations et ont fait part de leurs commentaires aux orateurs. Ils ont indiqué que les présentations étaient pour la plupart compréhensibles et que les « résumés détaillés » avaient été écris en pensant aux besoins des professionnels. Le personnel scientifique a cependant souvent omis de souligner qu'un transfert de connaissances avait eu lieu ou que leurs travaux avaient été utiles pour le processus de réglementation et/ou l'élaboration des politiques du ministère. La compilation des travaux montre cependant que les chercheurs ont fait leur possible pour répondre, durant la période couverte par l'étude, aux besoins en recherche des professionnels des océans et des habitats.

INTRODUCTION AND OBSERVATIONS

Key challenges of an applied research manager within DFO are to have her/his staff develop research proposals that are germane to the needs of the client, that are communicated in a timely manner, and that are delivered in manner comprehensible to the user; in our case the habitat/oceans practitioner (Oceans and Habitat and Enhancement Branch (OHEB); hereafter referred to as the practitioners). Beginning about 1997, the Marine Environment & Habitat Sciences Division's (MEHSD, Science Branch) management team agreed to a serious attempt to deliver research results to clients that were of high priority, that were timely and that were comprehensible (It must be remembered that these are not the only objectives of DFO's science personnel. They must also be prepared to provide advice on unexpected and emerging topics, often one's that have not been the focus of local empirical studies. Ability to succeed in this area, in part, depends upon their staying abreast of international science, and working at a high level of scientific competence. In addition, they can be called upon to influence policy. Their ability to be successful, in part depends on their scientific stature, which may come from being involved in extra-Regional and even international science).

How does an applied research organization develop their high-priority research question list, and how do they ensure the question as pictured by the client, is addressed? In-house research scientists can be one source of questions; applied scientists are expected to be prophetic in the area of human societal problems needing scientific resolution. Another source is science clients (who often may have little or no scientific training), in our case the practitioners, who indeed have perspectives on high priority research questions. Department of Fisheries and Oceans' Pacific Region developed, in 1997, an annual forum for habitat/oceans research question development, with each meeting co-chaired by the practitioners and science staff. Here, science staff outlined their skills, areas-of-specialization and perceived research priorities; the practitioners then presented their high-priority problem areas. Facilitated discussion provided a short list of problem areas. Scientist/practitioner teams were developed around each chosen problem area and the teams had a few weeks to develop a tractable question(s); to develop a research proposal that would attempt to answer the question(s); and to submit the proposal to the appropriate funding program. [Science staff, during the five year period 1997 through 2002 had competitive access to upwards of $5M annually from the Environmental Sciences Strategic Research Fund (ESSRF) managed by the National Coordinating Committee – Environmental Sciences Program (NCC-ESP). Each regional environmental science manager was a member of the NCC-ESP].

Given this concerted effort to work with clients and to even co-write research proposals, how well has MEHSD staff done in meeting the science needs of their clients; in particular the delivery of useful knowledge in both a timely and comprehensible manner? We were also keen to know if the advice had impact on the regulators and/or on Departmental policy.

MEHSD has a tradition of annual All-Staff meetings where staff from the five work sites are brought together to discuss research, to address common problems and work through

a theme. It was decided the 2002 (November 27th/ 28th) meeting theme would be "Applied environmental science - meeting the needs of the Habitat/Oceans practitioner?"; chosen in an attempt to answer the questions posed above regarding the setting of research priorities. A retrospective look at research accomplishments between 1997 and 2002 was provided at this meeting, with a focus on Environmental Sciences Strategic Research Fund (ESSRF) projects.

Project leaders (MEHSD Science Branch staff only) made 23 presentations, and the extended abstracts of each are the subject of this report (see pages 5 through 101). A panel of practitioners [Bonnie Antcliffe (OHEB, Regional Headquarters), Mel Shang (Habitat Management, South Coast Area), Bruce Shepherd (Habitat Management, North Coast Area), Kelly Francis (OHEB, Regional Headquarters), Andrew Morgan (Aquaculture Division, Regional Headquarters) and Brenda Bauer, (A/Director, Central Coast Area)] judged each presentation for coherence and clarity of presentation. Each speaker was asked, where possible, to describe impact of advice (the panellists were asked to comment on this criterion and usefulness of the advice when judging). (It should be noted that a number of the presentations stemmed from research that had emanated from proposals developed using the science/practitioner team approach outlined above.) Senior scientist, Colin Levings, acted as facilitator to the panel. The practitioners chose the Ken Shortreed-led study, "Current limnological status of Owikeno Lake" as the winning work, with honourable mention to Dr. Peter Ross' study, "Marine mammals as sentinels of marine ecosystem contamination in British Columbia". The panelists agreed that all work presented was deemed a priority by the clients, and that for the most part, knowledge had been delivered in a timely and comprehensible fashion.

Science Branch has, over the recent past, found it difficult to engage DFO clients in fora designed to identify research themes or in the prioritizing of client-driven problem areas requiring scientific input. Our annual MEHSD/client meetings to set research priorities are no exception. For the present meeting the MEHSD organizer had to nudge Directors and Area Chiefs beyond the deadline to commit staff to the meeting. Once, however, commitments were made, attendance and participation by clients was good. Some of the post-meeting feed back included:

- "Thank you for the invitation…to provide input. It was enlightening to hear…so much work is underway within Science. The reality in my…world is that there are questions to be answered that are not…controversial enough to acquire the priority status of Aquaculture and Oil & Gas…I understand the necessity to focus the Science studies on these larger issues…however, the issues that some of us deal with, on a daily basis, do not receive the attention." Margaret Wright, South Coast.;

- "…my thanks for the invite!" Bruce Shephard, Chief Habitat and Enhancement Management, North Coast. Bruce provided a list of research needs (See Appendix 1);

- "I thoroughly enjoyed your meeting and believe my Division can develop several partnership projects with your staff…I'm sure I could secure funding for a number of your staff and would like to discuss this with you…". Mel Sheng, Habitat and Enhancement, South Coast;

- "I enjoyed all the presentations. It was valuable to hear what research has been done and to know what direction is being taken in the future…Although habitat management staff are often involved in posing questions to science, they seldom get involved in discussing project design or modifications to projects once they get underway…A little more 'hands on' from HM (Habitat Management) staff could benefit both the researchers and the managers alike. I for one, find it very beneficial to work with habitat science staff…I…look forward to participating in similar reviews in future". Rob Russell, Habitat and Enhancement, South Coast;

- "Thanks John for your invitation and your encouragement of our participation. It's very gratifying to see this kind of outreach from Science…". Ron Kadowaki, Area Director, South Coast; and

- "…thanks…for the opportunity to participate in such a successful workshop." Andrew Morgan, Aquaculture Division, Regional Headquarters.

It appears the formula used in developing this forum was satisfactory to both the practitioners (see immediately above) and the scientists (their attendance and participation was excellent, and their verbal feedback positive). Scientific staff presentations were delivered with clarity, and the "extended abstracts" (see pages 5 through 101) delivered on time, and, for the most part, written with the non-specialist in mind. There is room for improvement, however. First, few presenters provided an indication of the knowledge transfer process, nor gave insights on the impact their work has had on the regulatory body or on Departmental policy (Panel members did, however, considered these factors from their perspective). Secondly, timeliness of reporting to clients was rarely discussed, though it is known that for a number of the studies the results have had a large impact on the regulatory agency (Departments of Environment and Fisheries and Oceans) e.g. Colin Levings' "A comprehensive study of Britannia mine's ecological impact to assist in resolving an acid mine drainage problem" (Page 86) and the Birtwell/Korstrum ("Yukon Placer Authorization and current research on the effects of sediment on chinook salmon") and Bradford ("The biology of chinook salmon in the Yukon River Basin and the 2002 Yukon Placer Authorization review") Yukon placer study (Pages 36 and 53 respectively).

Conclusions

1. Given the appropriate forum, habitat/ocean practitioners interact well with Science Branch staff to develop research priorities, and to critique science

feedback; indeed some requested more interaction than merely at the research proposal writing stage;

2. It may be that the less high profile, but quite possibly the more important problem areas of the practitioners can be overlooked by the research priority-setting process. (This may be due to the rules and criteria of the Department's Strategic Science Funding process. Researchers are requested to focus on national rather than regional problems. As well, Science Branch A-base budget has been significantly reduced over the past few years, leaving little discretionary monies for local research); and

3. Science personnel underestimate the need to document and publicize the impact of their advice on Departmental decisions and policy.

EXTENDED ABSTRACTS BY SECTION

MARINE ENVIRONMENTAL QUALITY SECTION

WHY DO WE NEED A HYDROCARBON BENCHMARK FOR THE QUEEN CHARLOTTE BASIN BEFORE DEVELOPMENT OF B. C. OFFSHORE OIL?

Walter Cretney

The short answer is that without an appropriate hydrocarbon benchmark the government will be faced with a scientific and legal nightmare in case ecological damage occurs through a catastrophic oil release. A lesson can be learned from the scientific and legal response to the Exxon Valdez oil spill into Prince William Sound, Alaska, on March 24, 1989. Because of litigation, two camps carried scientific investigations forward, one aligned to government and the other to industry. Except for pre-spill information, scientists were forbidden to exchange information between camps. Duplicate studies were carried out. Lawyers effectively directed researchers to concentrate on visible effects on charismatic species. Studies of interactions among organisms were discouraged.

The unhappy state of lawyer-managed research continued for two years after the spill until a civil settlement was reached between the government and Exxon. Even so, scientific divisions remained after the settlement. Scientists impugned the expertise of those in rival camps. Even under non-litigious circumstances scientists often disagree, but the continuing intensity of disagreement was enough to garner special attention by scientific magazines and the general news media. The tenor of feeling was reflected in articles with titles such as "State officials slow research on the effects of the spill" (Science, 22 May 1992), "Dispute over Exxon Valdez cleanup data gets messy" (Science, 7 May 1993) and "The two faces of the Exxon disaster" (New Scientist, 22 May 1993). Industry scientists accused government scientists of lacking the expertise to properly identify sources of contamination in biota (Science, 7 May 1993). Government scientists intimated that industry scientists failed to take metabolic changes of oil into consideration (Science, 7 May 1993) and missed "hot spots" of contamination by doggedly adhering to statistical sampling designs (New Scientist, 22 May 1993).

Ecosystem studies were initiated by 1994, the largest of which was the 7-year, $23-million Sound Ecosystem Assessment (Science, 9 April 1999). But, ten years after the spill government, represented by the Exxon Valdez Oil Spill Trustee Council, and Exxon still disagreed on the lasting effects of oil on species. Science magazine (9 April 1999) noted the continuing disagreement with the statement that "[t]he company disputes the trustees' assertion that only two species, bald eagles and river otters, have fully recovered." A further complication in the assessment of recovery was emergent evidence

that climate change, not oil, may be the key ecological driving force in the Gulf of Alaska (Science, 9 April 1999).

Although it is clear that a hydrocarbon benchmark alone would not have resolved the oil-versus-climate question, an appropriate pre-spill benchmark could have settled a continuing controversy over sources of hydrocarbons in the Sound and Gulf. Background hydrocarbons have come from marine and terrestrial biota, combustion processes, seep oils, eroding shales, and coal seams. Using multivariate techniques, researchers have made substantial progress in assigning samples to major sources. Yet, enough uncertainty remains to justify continued sampling and analysis.

The question of source would be mainly academic, were it not for litigation surrounding the Exxon Valdez oil spill. "If the background hydrocarbons consist principally of oil-derived materials, the fine [to Exxon] would be less than if coal was the source." (Mudge 2002). The distinction is important. Coal-derived hydrocarbons are up to a 1000-fold less bioavailable than oil-derived hydrocarbons. The long-term toxic effect of hydrocarbons depends on the bioavailability of the polycyclic aromatic hydrocarbon (PAH) fraction in source material. It may be that Alaskan marine organisms have adapted to seep-oil PAH inputs equivalent to or greater than inputs from Exxon Valdez oil-spill residues except in small, localised areas. If so, then an argument could be made that observed negative population level trends are unlikely to be a consequence of a continuing presence of Exxon Valdez oil.

Several benefits may accrue in obtaining a hydrocarbon benchmark before acute or chronic releases of hydrocarbons can occur from an offshore oil and gas industry. The scientific work proceeds in a non-litigious atmosphere. Scientists from government, industry, academia and NGOs can co-operate. Duplication of effort is avoided. Sampling decisions are made without the 'rush to action' imperative. A 'media circus' may be avoided, along with ensuing public disapproval. The potential is reduced for politicisation of issues.

References:

Mudge, S.M. 2002. Environmental assessment of hydrocarbons in Prince William Sound and the Gulf of Alaska: Identifying the source using partial least-squares. Environmental Science & Technology 36(11): 2354-2360.

ENVIRONMENTAL IMPACT OF CLASSICAL AND "NEW-ERA" ENDOCRINE DISRUPTING CHEMICALS

Michael G. Ikonomou

In recent years the Regional Dioxin Laboratory (RDL) has focussed on three areas: a) mass spectrometry-based analytical method development for the determination of "new-era" contaminants in environmental samples; b) providing analytical support to Regional and National programs; and c) conducting research into the sources, distribution, and fate of classical and "new-era" contaminants in the environment. By responding to the demands of DFO's toxic chemicals research we have been able to substantially increase the RDL's analytical capabilities. Not long ago the RDL had the capability of detecting and quantifying ~50 organochlorine contaminants, including polychlorinated biphenyls (PCBs) and polychlorinated dibenzo-p-dioxins and furans (PCDD/Fs). Currently, we are capable of detection of over 1,000 contaminants (see "Method Development" in Figure 1) in tissue, sediments, water and industrial and municipal effluents, etc.

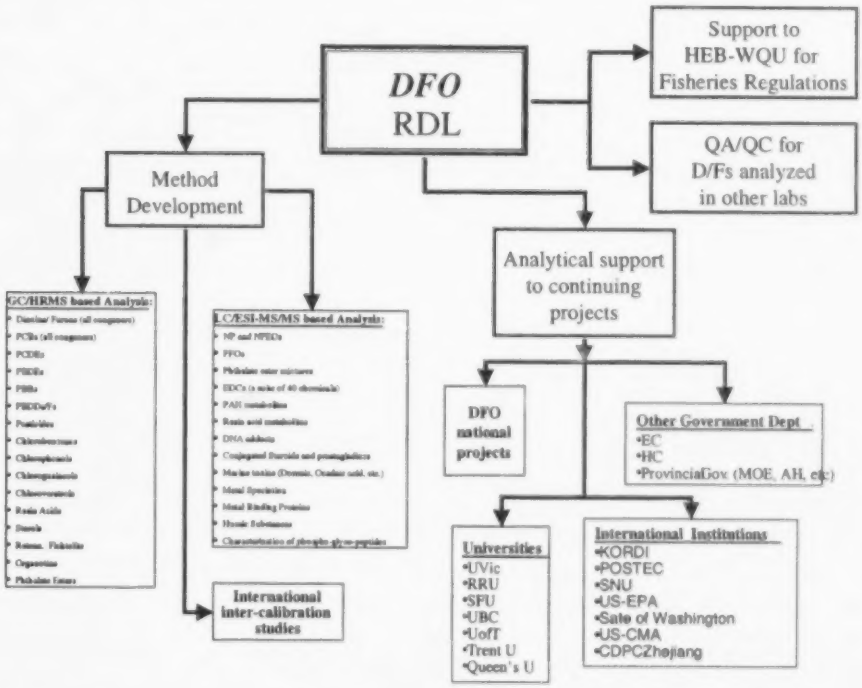

Figure 1. Flow diagram showing role of RDL in supporting internal clients and collaborative research with national and international agencies.

The RDL has long been providing analytical support to Habitat and Enhancement Branch's (HEB) Water Quality Unit (WQU) and more recently to Canadian Coast Guard's contaminants program. Samples from HEB contaminants monitoring program

are analyzed for dioxins/furans and PCBs and fisheries are regulated according to the level of contamination measured. In the late 1980s, concerns for the discharge of PCDD/Fs by BC pulp mills were raised upon their detection in sediments and biota adjacent to several coastal mills. These highly toxic contaminants were formed in the chlorine-based bleaching process used by coastal mills. Of primary concern was the amount of 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD). With the detection capabilities of the RDL's high-resolution instrumentation, additional PCDD/F congeners were detected allowing for total toxicity equivalence (TEQ) assessments and for the identification of PCDD/F patterns for the industry (Yunker *et al.*, 2002). Figure 2, shows the decrease of PCDD/F TEQ in various coastal biota following the implementation of provincial maximum allowable discharge regulations in the late 1980s.

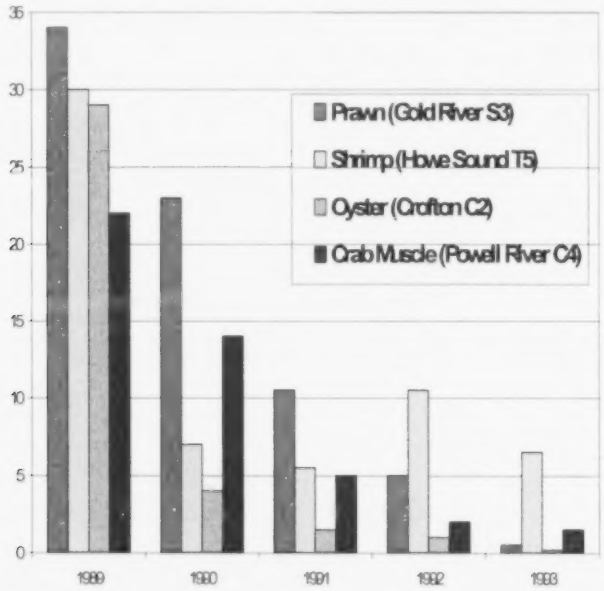

Figure 2. PCDD/F TEQ in various coastal biota following the implementation of provincial maximum allowable discharge regulations in the late 1980s.

The congener-specific detection and quantification of PCBs allows for the incorporation of PCBs into a total TEQ for a given location. The incorporation of PCBs into total TEQs along with the continued bioavailablility of these persistent bioaccumulative toxins has led, since 1997, to a fixed area of fish harvest closures in BC.

The consistent, annual, congener-specific monitoring of PCBs and PCDD/Fs in commercially relevant species such as Dungeness crab (*Cancer magister*) has provided information which has been used to model and predict potential sources and fate of PCBs and PCDD and PCDDFs in BC coastal waters. One model (Sather *et al.*, 2001) allows for the prediction of common Aroclor sources from profiles found in biota (see Figure 3) for select harbour and pulp and paper mill sites.

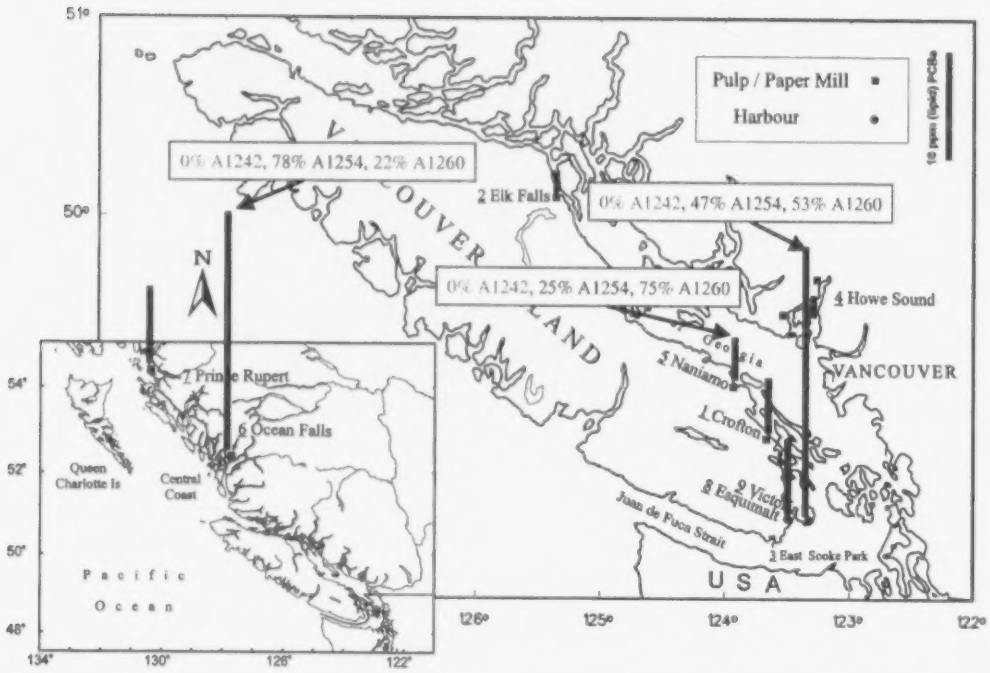

Figure 3. Common Aroclor sources from profiles found in biota for select harbour and pulp and paper mill sites.

Additionally, the RDL is involved in screening BC's coastal environment for new and previously unknown contaminants or contaminants of emerging concern. Brominanted Flame Retardants, the most infamous being polybrominanted biphenyls (PBDEs) have similar environmental properties to PCDD/Fs and PCBs. They are highly bioaccumulative, and thus magnify in concentration up the food chain; they are toxic and persistent in the environment. The RDL has shown how the PBDE levels in Arctic seals parallels world production figures for a common PBDE (Figure 4). Additionally, the doubling rate of this increase has shown to be 4-8 years in the Arctic, whereas the levels of PCBs and classical organochlorine pesticides, such as DDT have been decreasing as measured in the same samples. Figure 5 illustrates the current levels of PBDEs in crab hepatopancreas relative to other classical contaminants such as PCBs, PCDD/Fs and organochlorine pesticides. Considering that PBDEs occur at a similar magnitude as PCBs and organochlorine pesticides (i.e. ppm level) and several times greater than PCDD/Fs, they may significantly contribute to the overall toxicity in any environmental risk assessment. In addition, we have taken a similar pattern analysis approach as used with the PCB data to congener-specific PBDE data in order to more fully understand potential sources and the fate of these contaminants in marine and fresh water (i.e. Columbia and Fraser Rivers) ecosystems.

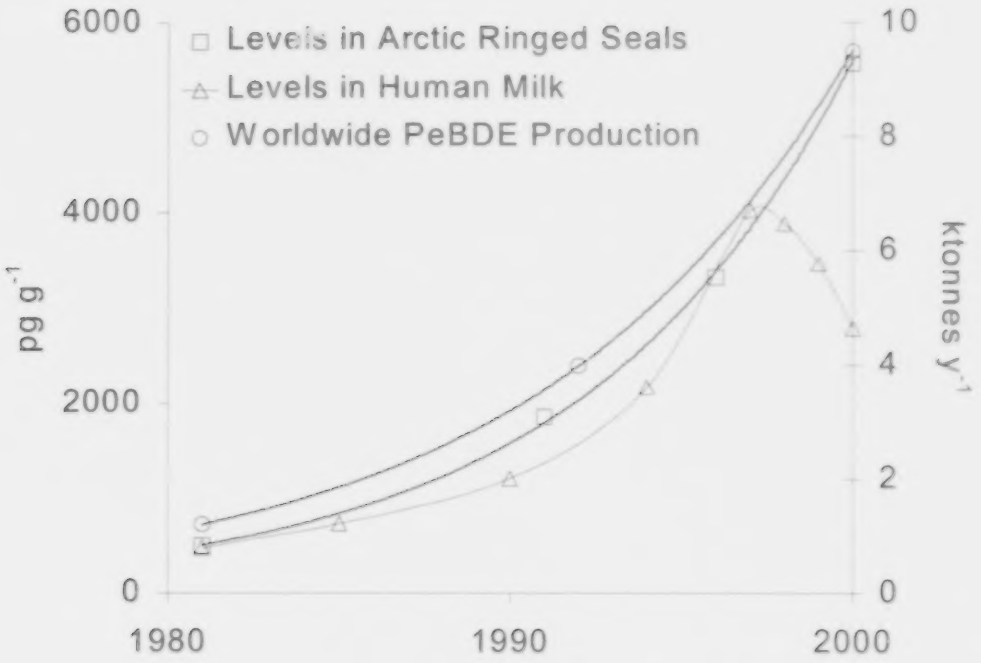

Figure 4. PBDE levels in Arctic seals parallels world production figures.

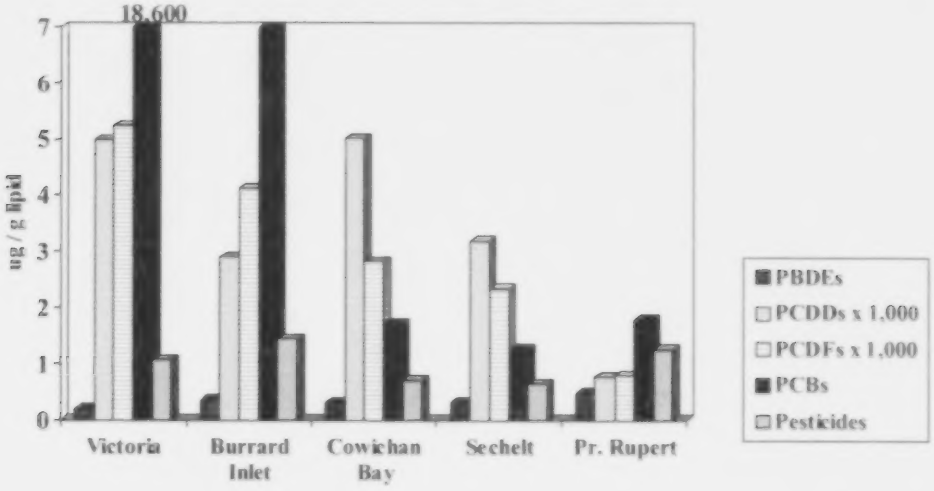

Figure 5. Levels of PBDEs and other classical contaminants in crab hepatopancreas from certain BC sites.

Lastly, the RDL is currently in the process of developing sensitive analytical methods to identify and quantify a new suite of contaminants which are non-persistant, non-bio accumulative and non-toxic, however, they are potent endocrine disruptors in sewage and

pulp mill effluents. Such compounds include, natural and synthetic steroidal estrogens, surfactants, plasticizers and phytoestrogens. A list of 40 such culprits has been formulated and a bioassay-directed fractionation procedure has been developed to screen samples and fractions of differing polarity for the identification of hormonally active compounds. The overall project involves not only the chemical characterisation and quantification of known or active (determined *in vitro*) compounds, but also the determination of whole organism effects in alevin and juvenile Chinook salmon exposed to effluents under laboratory conditions.

Acknowledgements

Many thanks to our collaborators (Wayne Knapp, Richard Addison, Sierra Rayne, Margaret Wright, Tom Smith, Bonnie Antlcliffe, Bob Devlin and many others) for their valuable contributions, and to our analysts and technical support staff Marc Fernandez, Cory Dubetz, Sheng-Suan Cai, Tasia Kotronia, Tim He and Paula Sather and to the many university co-op students) who made this work possible. Funding for this work was provided by DFO-Environmental Sciences Strategic Research Fund, Toxic Substances Research Initiative and National Contaminants Program.

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TRANSPORT AND FATE OF CONTAMINANTS IN THE STRAIT OF GEORGIA

Sophia C. Johannessen and Robie W. Macdonald

Contaminant research in the Strait of Georgia provides contaminant budgets, process studies and a historical perspective for recent measurements. Box models, spatial distributions and trends in contaminants facilitate efficient monitoring, development and application of appropriate indicators, prioritization of environmental threats, local and regional assessments, integrated management and the choice of marine protected areas The sources of contaminants to the Strait of Georgia are numerous. They include municipal outfalls, pulp mills, the abandoned Britannia mine, industrial, residential and agricultural runoff, shipping, aquaculture, and atmospheric transport both from within the drainage basin and from across the Pacific Ocean.

Many of the most persistent contaminants, particularly organic particles (metals, PCBs, PAHs and others), partition strongly onto solids. Recent work in the Strait of Georgia has focused on the transport, fate and budgets of particles and organic carbon, as a foundation for determining the likely pathways of the particle-active contaminants. In collaboration with other government scientists, we have collected 20 sediment cores from the Strait of Georgia, Vancouver Harbour and Howe Sound (Figure 1) and analyzed them to determine the accumulation rates of sediment and organic carbon at each site and the depth and rate of sediment mixing by benthic organisms.

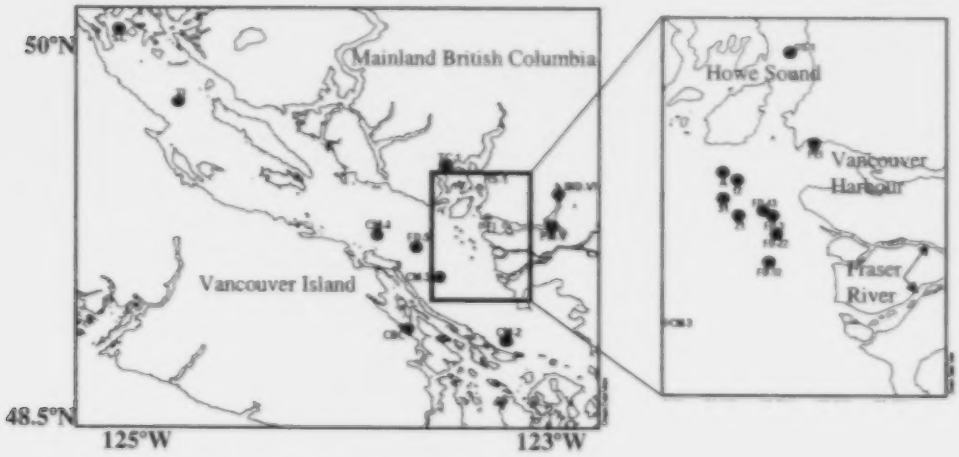

Figure 1. Sample locations for sediment core collection sites in the Strait of Georgia, Vancouver Harbour and Howe Sound. Sediment trap mooring sites were at stations CM2, CM3 and CM4.

The determination of sediment accumulation rate and surface mixing is essential to interpreting contaminant patterns in sediment cores. For example, sediment cores from Howe Sound contain mercury distributions that are consistent with a pulse of mercury in about 1965-1970 coincident with the maximum mercury discharge of the FMC chlor-alkali plant, once sediment accumulation and mixing rates are taken into account.

The sediment and organic carbon accumulation rates calculated from the cores were also combined with input values taken from the literature to produce budgets for particles and organic carbon (Figures 2-4). The Fraser River dominates the particle budget, providing approximately 64% of the particles to the Strait. Other rivers are the next largest source (18%), while solids derived from human activities are insignificant to the total budget. (Sewage, pulp mills and aquaculture combined supply < 0.2% of the total particle load.) Human activities contribute more to the carbon budgets, supplying about 4% of the particulate and 7% of the dissolved organic carbon. However, the Fraser River and *in situ* primary production by phytoplankton supply most of the organic carbon to the Strait. Essentially all the particles and particulate organic carbon that enter the Strait become buried in its sediments, while the dissolved organic carbon is oxidized or transported out of the Strait.

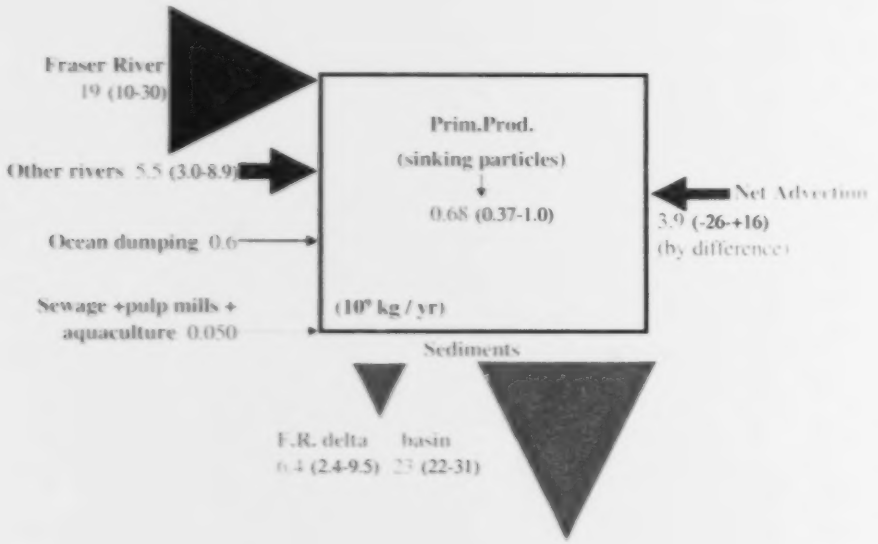

Figure 2. Particle budget for the Strait of Georgia and contiguous fjords. Particle fluxes are in 10^9 kg/ yr. The sediment accumulation rate for the whole Basin was extrapolated from the rates calculated for individual cores, and the values in brackets represent the range of reasonable values that could be calculated in that way.

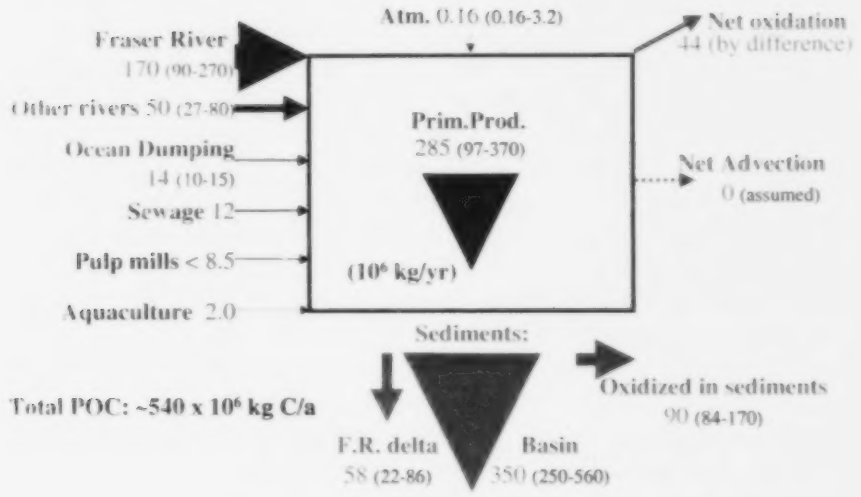

Figure 3. Particulate organic carbon budget for the Strait of Georgia and contiguous fjords. Fluxes are in 10⁶ kg/yr. Source values in brackets represent ranges of published values. The rates of organic carbon burial and oxidation for the whole Basin was extrapolated from the rates calculated for individual cores, and the values in brackets represent the range of reasonable values that could be calculated in that way.

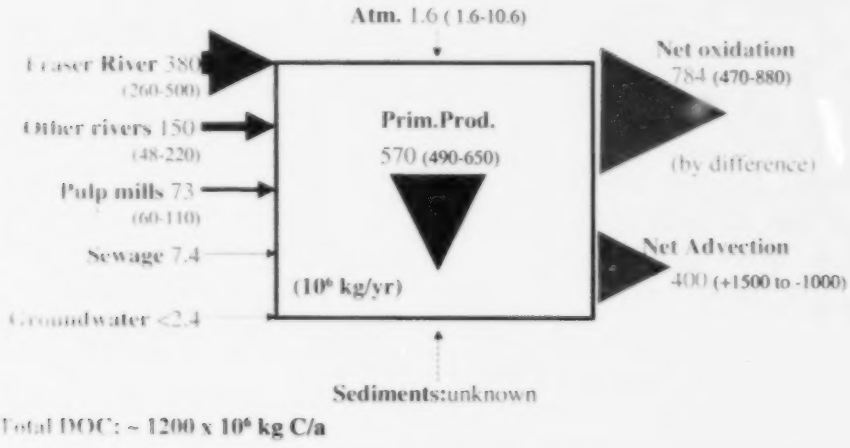

Figure 4. Dissolved organic carbon budget for the Strait of Georgia and contiguous fjords. Fluxes are in 10⁶ kg/yr. Source values in brackets represent ranges of published values. The rate of organic carbon advection was calculated as the product of the measured, water column concentration of dissolved organic carbon and the (quite uncertain) net flux of water out through Juan de Fuca Strait. The values in brackets represent the range of reasonable values that could be calculated in that way. Net oxidation was calculated as the difference between the total inflow and outflow values, to make the budget balance.

While box model budgets describe the relative importance of various sources and sinks, and provide context for individual measurements, sediment traps can help to describe the spatial and seasonal variability of the particle fluxes. Sediment traps were moored at three locations in the central and southern Strait (Figure 1). They collected sinking particles over ten-day intervals at 150 m for two years at all three stations and then at 150, 225 and 300m at station CM3 for a third year. The traps showed increasing particle flux from north to south in the Strait. At the southernmost station, in Saturna Basin (CM2), the particle flux into the sediment trap and the sediment accumulation rate calculated for a sediment core collected at the mooring site were essentially equal, while the traps at the two more northerly stations (CM3 and CM4) recorded only 26 and 17 %, respectively, of the sediment accumulating in sediments at these sites. This discrepancy, together with an analysis of the chemical and isotopic composition of the particles, suggests that an important component of the sediment transport takes place northward along the bottom of the central Strait, as shown in Figure 5.

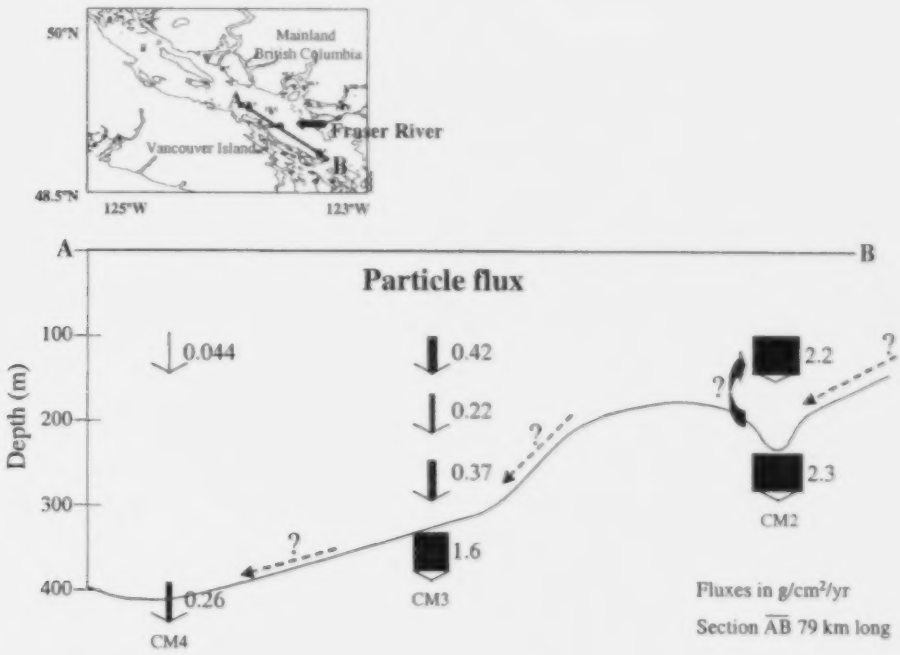

Figure 5. Particle fluxes (g /cm2 /yr) to sediment traps and sediment cores at stations CM2, CM3 and CM4. Bottom transport of particles from south to north may explain the large difference between the trap and core fluxes. At station CM2, resuspension of bottom sediments may increase the sediment trap flux.

The composition of the vertical flux at all three stations, and particularly at the station (CM3) opposite the main mouth of the Fraser River, varied throughout the year from dominantly terrigenous to dominantly marine-derived. These two sources of particles – terrigenous and marine - scavenge and transport contaminants differently. Terrestrial runoff delivers industrial, agricultural and municipal products to the Strait of Georgia

from within the drainage basin. On the other hand, the marine organic particles formed through primary and secondary production are often good at scavenging organochlorine compounds and mercury, thus providing a path to remove contaminants entering the Strait directly through air-sea exchange. Accordingly, the variation in the source of the sinking organic matter is an important underpinning for understanding the implications of contaminant fluxes to the bottom at these sites.

A list of related publications from the last five years is attached below. All of the listed publications were funded entirely or in part by the Environmental Science Strategic Research Fund, which was discontinued in 2002. Given sufficient funding, future work will concentrate on contaminant transformation processes and on present-day contaminant budgets for mercury, PCBs, antibiotics and other pharmaceuticals.

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ARCTIC OCEAN EXPLORATION: CLIMATE AND CONTAMINANTS

Fiona A. McLaughlin and Robie W. Macdonald

Our current research program in the Arctic began in the mid-1980s. Over the past fifteen years we have mounted over twenty expeditions, ranging from small scale investigations in the Beaufort Sea to an ambitious international two-ice-breaker expedition that crossed the entire Arctic Ocean, entering from the Pacific and exiting from the Atlantic. We took part in a year-long experiment (SHEBA – Surface Heat Budget of the Arctic) on a ship that was frozen into the permanent ice-pack and, in 2002, led an international three-ship program in the Canada Basin. During the past 15 years the focus and funding have evolved from the development of science to support oil and gas regulation (Northern Oil and Gas Program, NOGAP), to the understanding of risks associated with long-range contaminant transport (Northern Contaminants Program, NCP), to the assessment of how global climate change is manifesting itself within the Arctic (Strategic Science Fund, SSF; Climate Change Action Fund, CCAF). Our studies have shown us that, despite its remoteness, the Arctic Ocean is globally connected and is no longer the pristine environment once imagined (Figure 1). Indeed, the Arctic appears to be especially vulnerable to contaminants and climate change.

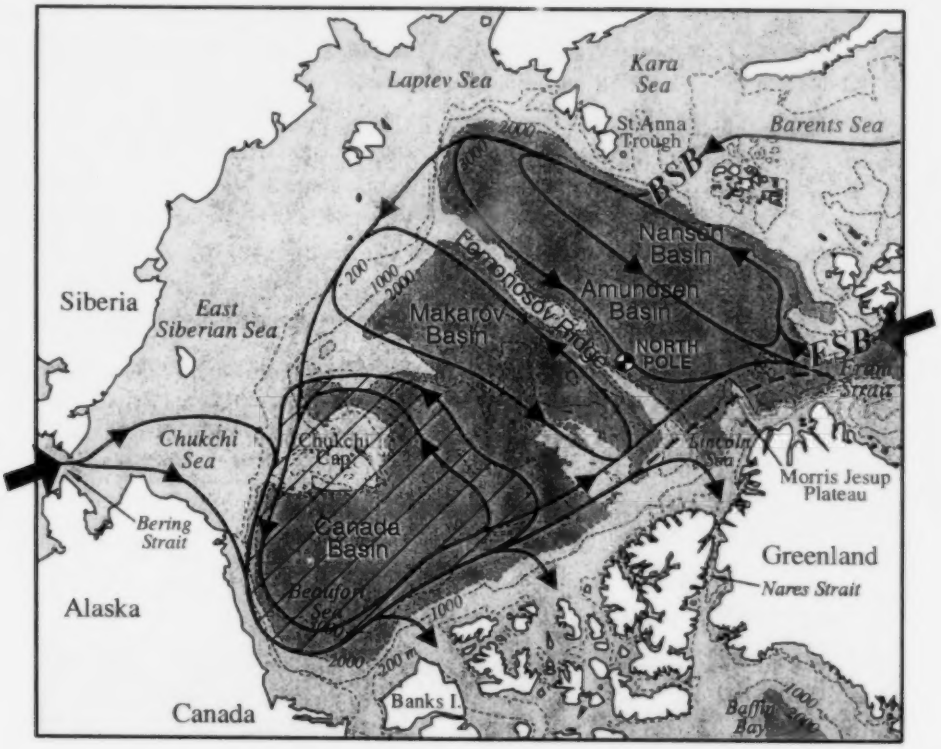

Figure 1. Arctic Ocean map with major bathymetric features and circulation of Atlantic (light) and Pacific (dark) inflow.

Organochlorines, manufactured and applied in the south, are delivered to the north by the atmosphere and the oceans. Our time-series measurements of HCH (hexachlorocyclohexane) in the Canada Basin have shown that surface waters under the permanent pack ice of the Arctic Ocean contain the highest α-HCH concentrations in the world (Figure 2), despite international agreements that led to the reduction of atmospheric concentrations during the 1980s and 1990s. Time series like those we've collected for HCH, together with studies comparing the sources, distribution and sinks for compounds with varying physical properties, have led to a much better understanding of why particular contaminants released in temperate and sub-tropical regions of the Northern Hemisphere put Arctic ecosystems at risk. Our work on hydrocarbons, metals, and organochlorine compounds in the Arctic has been published in over 30 journal articles, 10 book chapters and in numerous reports and presentations. This work has led to invitations to contribute to - or lead - Arctic contaminant assessments including the Arctic Monitoring and Assessment Program (AMAP I and II) reports and the Canadian Arctic Contaminants Assessment Reports (CACAR II and II).

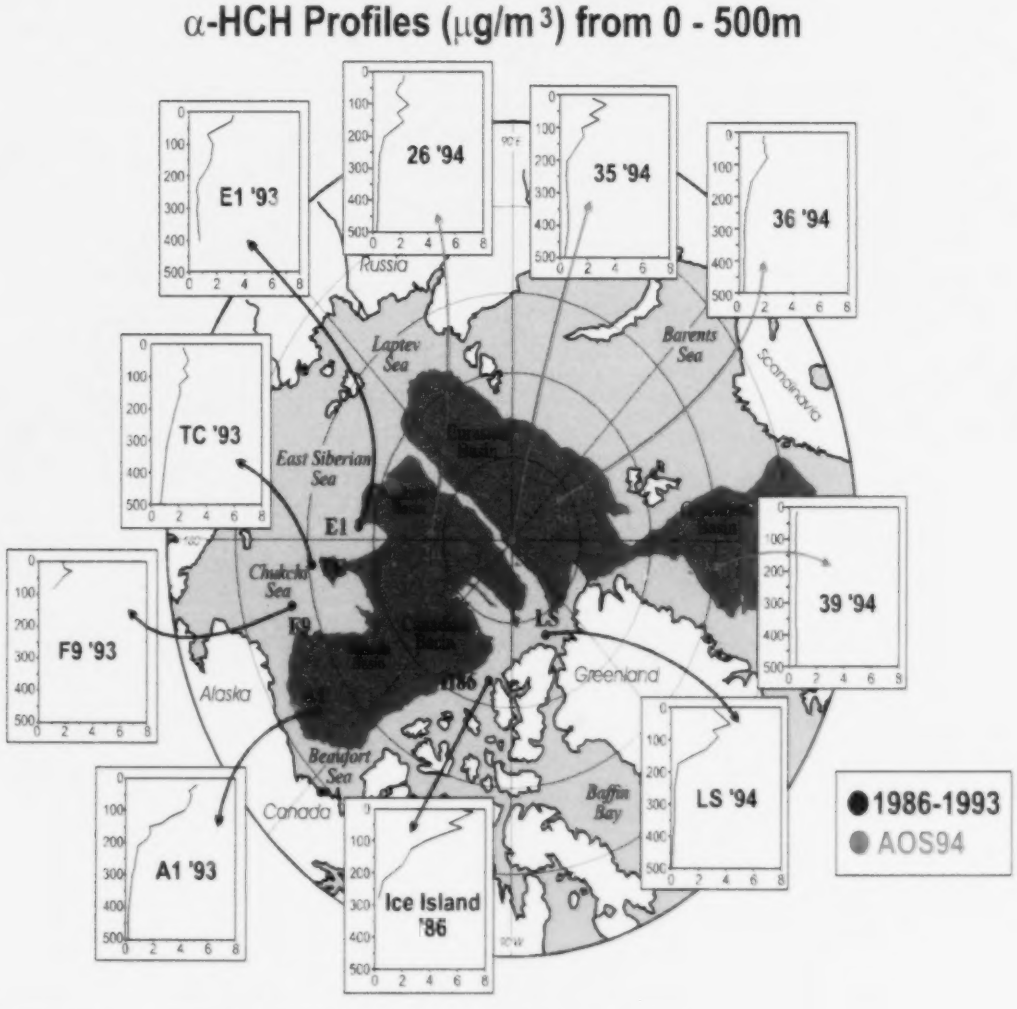

Figure 2. Distribution of HCH in the upper waters of the Arctic Ocean

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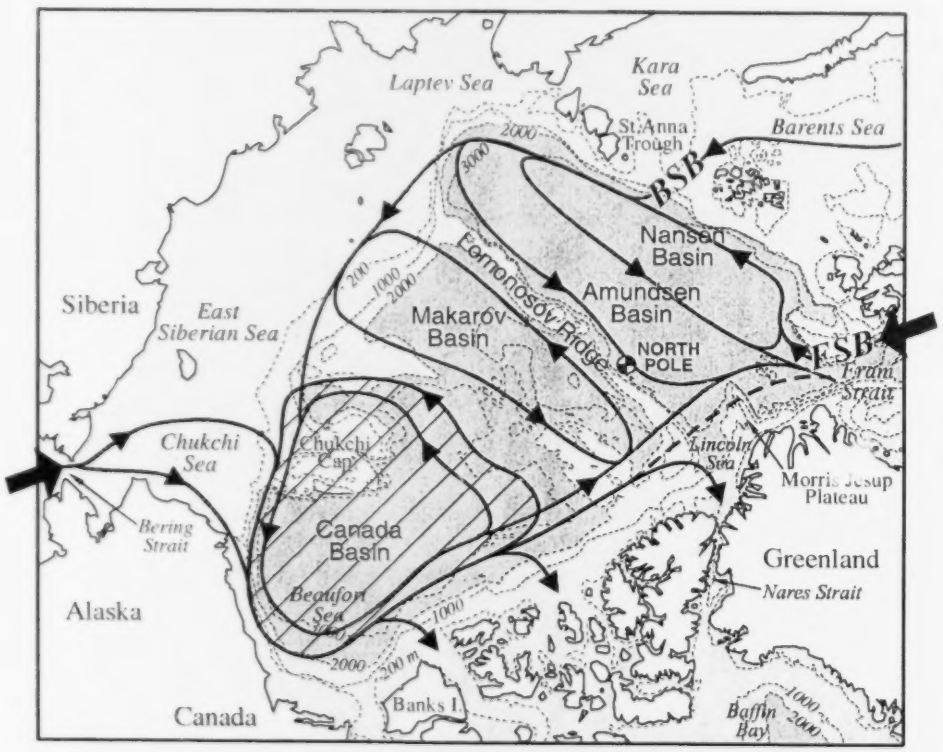

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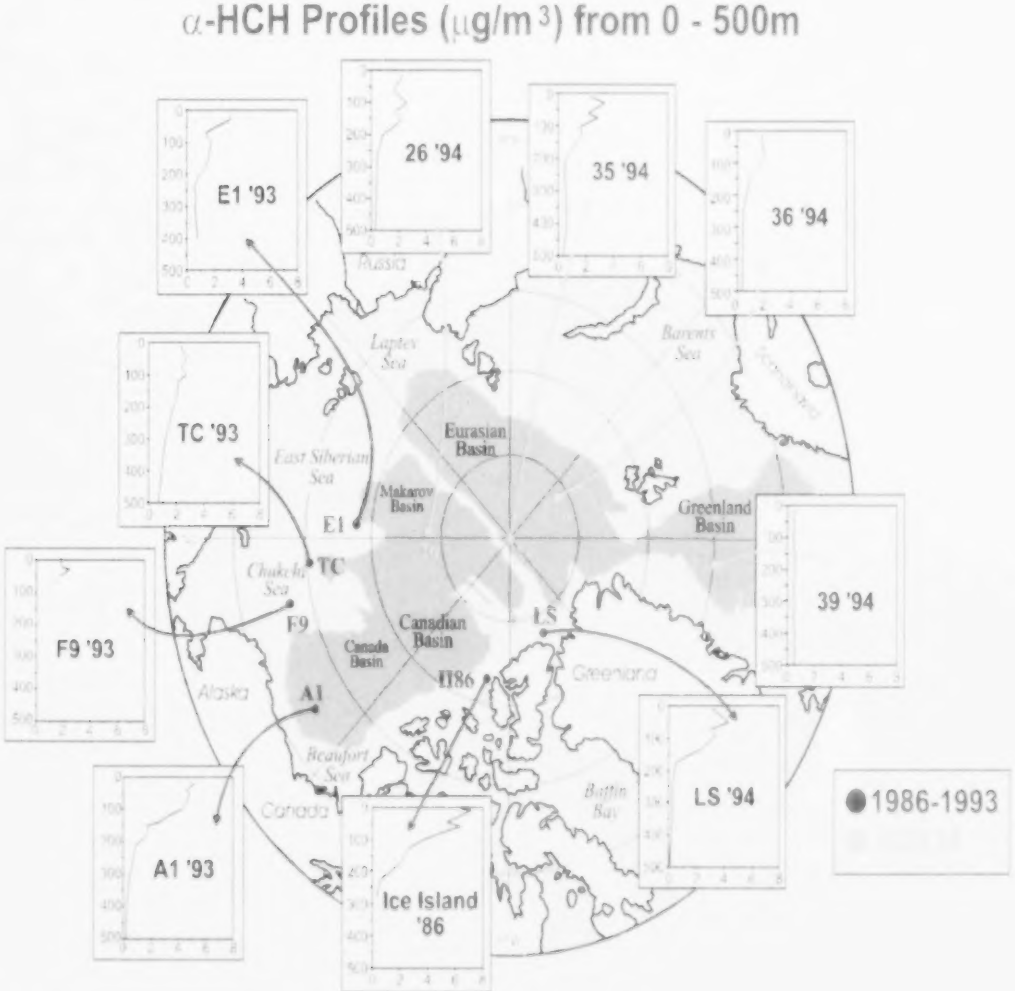

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Have these scientific endeavours had an impact? In projects as large as the NCP where there are so many facets to the science, it is difficult to single out any one person or project. Nevertheless, our work together with the efforts of 19 other individuals was acknowledged by "The Head of the Public Service Award" which was presented to Canada's negotiating team for the Global Convention on Persistent Organic Pollutants. Together, we produced the science that underpinned Canada's successful initiative to get the "dirty dozen" POPs eliminated. Although these contaminants continue to cycle in Arctic ecosystems, we have every reason to believe that, with time, classical contaminants like PCB, toxaphene, DDT and chlordane will decline to levels where they no longer cause us concern. Our understanding of how these contaminants enter and magnify through environmental pathways now provides a much better basis for screening new compounds proposed for release to the environment.

The Arctic is also a region where the impacts of climate warming will be observed first. Alarming reports about the thinning of the polar ice-cap have captured public attention, identifying the urgency to understand the impacts of such change on the Arctic ecosystem and its capacity to respond. Before 1985 the Arctic Ocean was thought to be a static ocean, unchanging in nature, and that it did not play a role in the global climate system. DFO research has helped to challenge this view by showing that a major change in Arctic Ocean circulation occurred in the early 1990s which was, in turn, due to a change in atmospheric circulation (Figure 3). Research conducted now in the Canada Basin is tracking these changes as they work their way across the Canada Basin and investigating freshwater export pathways (through the Canadian Archipelago or Fram Strait). The export of freshwater from the Arctic Ocean balances the global freshwater budget and the route that it follows, either via Fram Strait or the Canadian Archipelago, affects global ocean circulation and global climate. The results, and impact, of our research on recent changes in the Arctic Ocean can be found in the literature where we have contributed 12 journal articles. We have also been invited to make numerous presentations at national and international meetings. Furthermore, our work has led to an invitation to contribute to the Arctic Climate Impact Assessment (ACIA) now in preparation for the International Arctic Science Committee. Our leadership in conducting arctic research is demonstrated by requests from the US, Japan, China, Russia and others to join our Arctic expeditions and to collaborate on the interpretation of data.

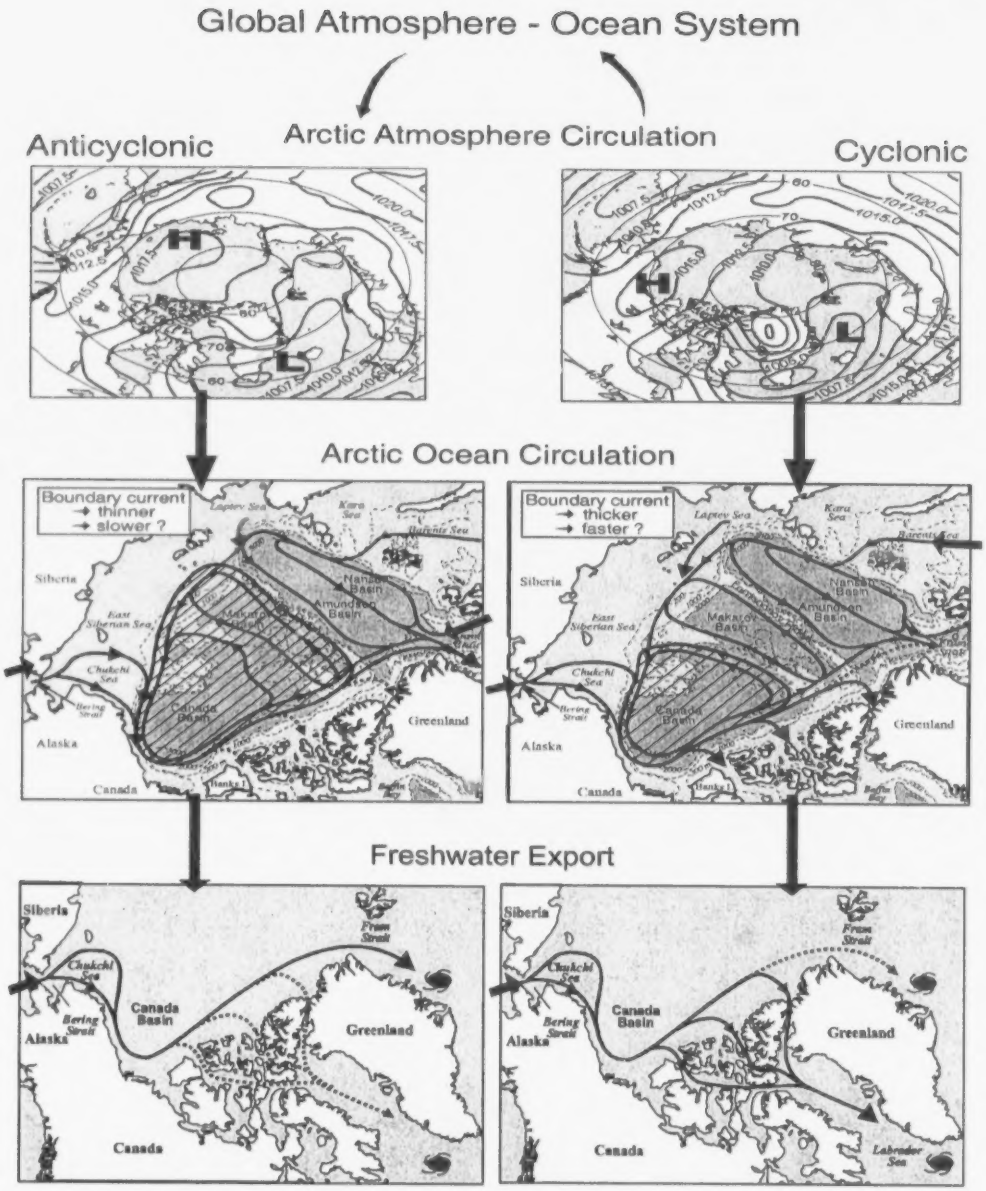
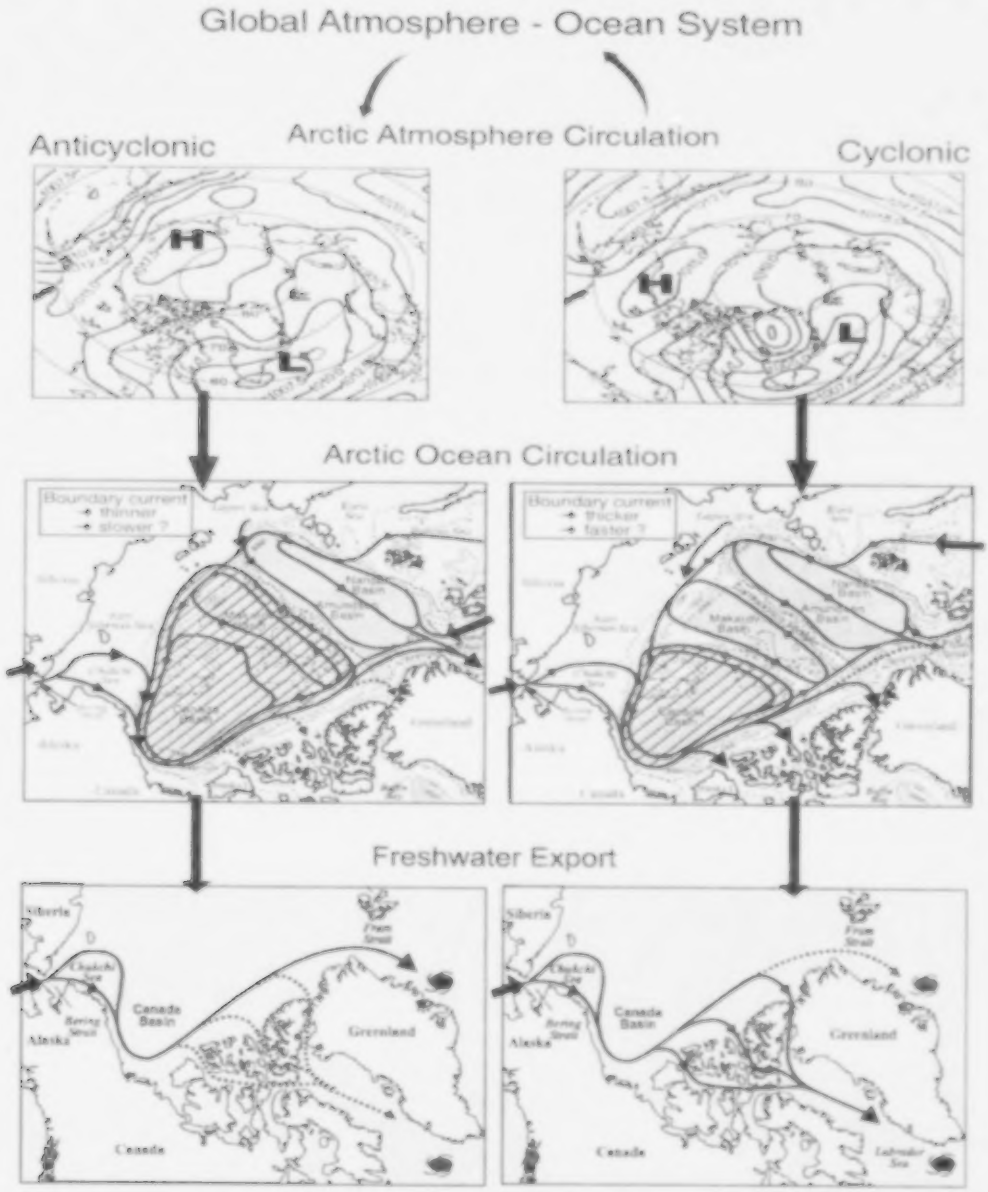


Figure 3. Two Arctic atmosphere-ocean modes: a hypothesis. During the anticyclonic mode (i.e. reduced cyclonic atmospheric circulation), Atlantic inflow is weaker and Atlantic-origin water in the Arctic Ocean is colder, the boundary current is thinner, transport may be slower, the Atlantic/Pacific front is located over the Lomonosov Ridge and freshwater exits primarily through Fram Strait. During the cyclonic mode (i.e. increased cyclonic circulation) Atlantic inflow is stronger and Atlantic-origin water in the Arctic Ocean is warmer, the boundary current is thicker, transport may be faster, the Atlantic/Pacific front is shifted eastward over the Mendeleyev Ridge and freshwater exits primarily through the Archipelago



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MARINE MAMMALS AS SENTINELS OF MARINE ECOSYSTEM CONTAMINATION IN BRITISH COLUMBIA

Peter S. Ross

Marine mammals are often considered 'charismatic megafauna', attracting the interest of the public and conservationists on a regular basis. However, the habits and ecological niches of these animals often render them prone to becoming contaminated with persistent and toxic chemicals. Most are long-lived, and accumulate contaminants more rapidly than they can eliminate them. Many occupy high positions in marine food chains, consuming large quantities of fish, and in some cases, even marine mammals. Marine mammals can therefore be considered as unwitting targets for toxic chemicals such as polychlorinated biphenyls (PCBs) and organochlorine pesticides. Such is the nature of life at the top of the food chain in today's industrial world.

We have been increasingly viewing marine mammals as 'sentinels' in the coastal waters of British Columbia. The persistent and bioaccumulative nature of many toxic chemicals ensures that they become increasingly concentrated in marine mammal food chains. Marine mammals can therefore provide us with a useful scientific tool which provides an integrated measure of the state of our coastal environment.

Through our combination of field and laboratory research, we have been attempting to answer two basic questions. First, 'What can marine mammals tell us about the extent of contamination of the coastal environment?' and secondly, "Is the health of marine mammals being adversely affected by exposure to high levels of toxic chemicals?'. Both questions are relevant to different stakeholders, ranging from those concerned with marine mammal conservation to those attempting to mitigate pollution sources.

Upon finding BC's killer whales to be highly contaminated with PCBs, we explored the factors that might explain why this was. Females were less contaminated than males as a result of their offloading of toxic chemicals via mother's milk to their offspring. Males became more contaminated as they got older. Transient killer whales were more contaminated than resident killer whales, likely reflecting their diet of contaminated marine mammals compared to the residents' diet of less contaminated fish (Ross *et al.*, 2000). Southern residents were more contaminated than northern residents, likely reflecting the consumption of prey from the more industrialized parts of southern BC and northern Washington State (Figure 1). Killer whales are essentially telling us that PCBs are accumulating in their bodies as a result of the persistent and bioaccumulative nature of these and other chemicals.

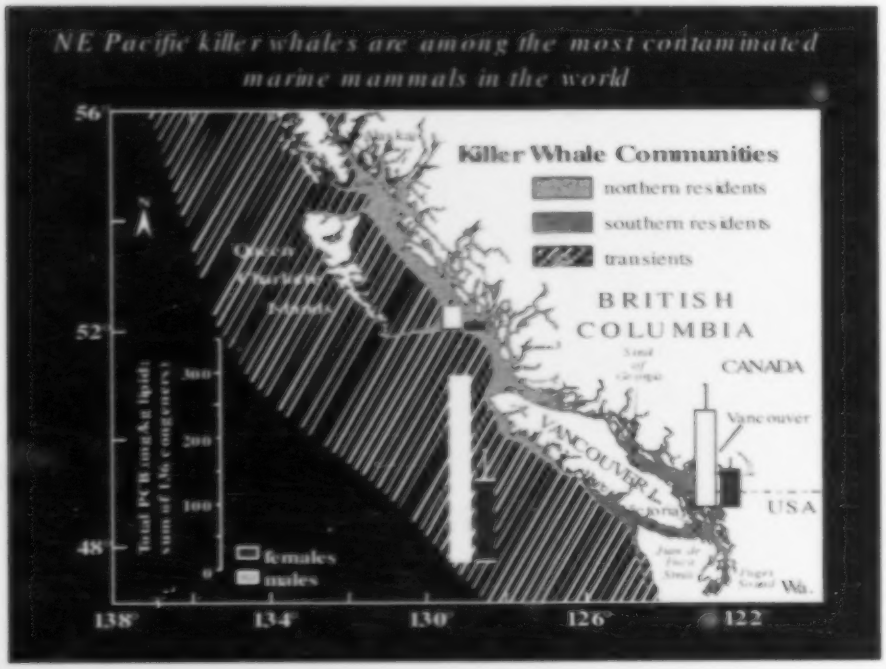
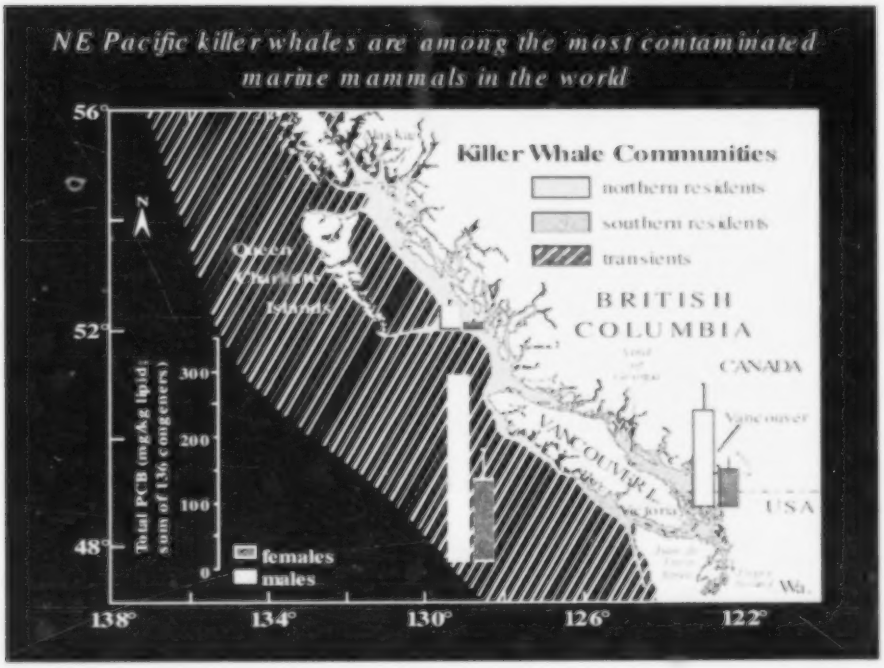


Figure 1. Killer Whale communities found in coastal waters off B.C. and Puget Sound, Washington.

While killer whales provide a broad scale signal of contamination from the northeastern Pacific Ocean, harbour seals (*Phoca vitulina*) are providing us with more site-specific information on the extent of coastal contamination in BC and Washington State. We take small blubber biopsies from healthy, same-age, live-captured seals for contaminant analysis, after which they are released back into their environment. We have found that, despite improvements after the implementation of controls in the late 1980s and early 1990s, dioxins and furans continue to contaminate harbour seals in parts of the Strait of Georgia. These contaminants are by-products of the pulp and paper industry and of the pentachlorophenol (PCP) treatment of wood chips.

We also found that harbour seals from Puget Sound were highly contaminated with PCBs, compared to their counterparts in the Strait of Georgia and the more remote Queen Charlotte Strait (Figures 2 and 3). This is likely due to i) a history of industrial leakage and contamination of waterways and sediments in the Puget Sound area; and ii) the lower burial rates for contaminants in Puget Sound sediments as a result of its bathymetric features and low fresh water inputs relative to the Strait of Georgia.



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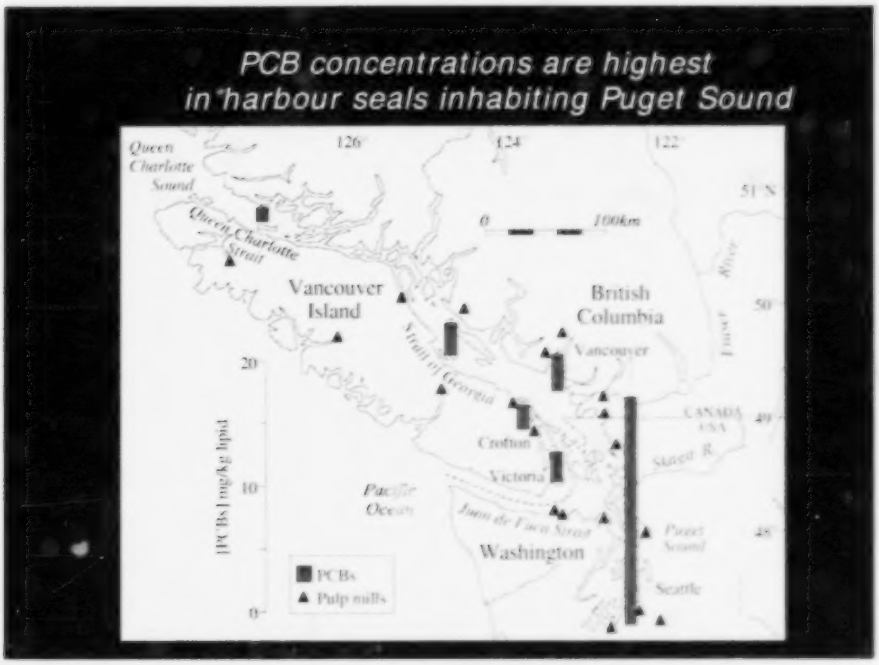


Figure 2. PCB concentrations in both Puget Sound and Strait of Georgia Harbour seals.

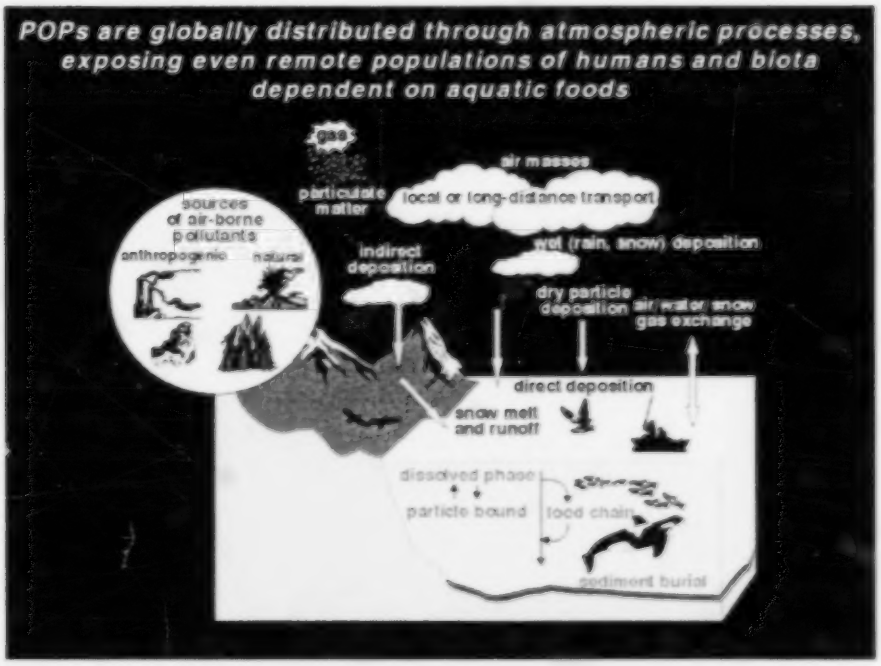
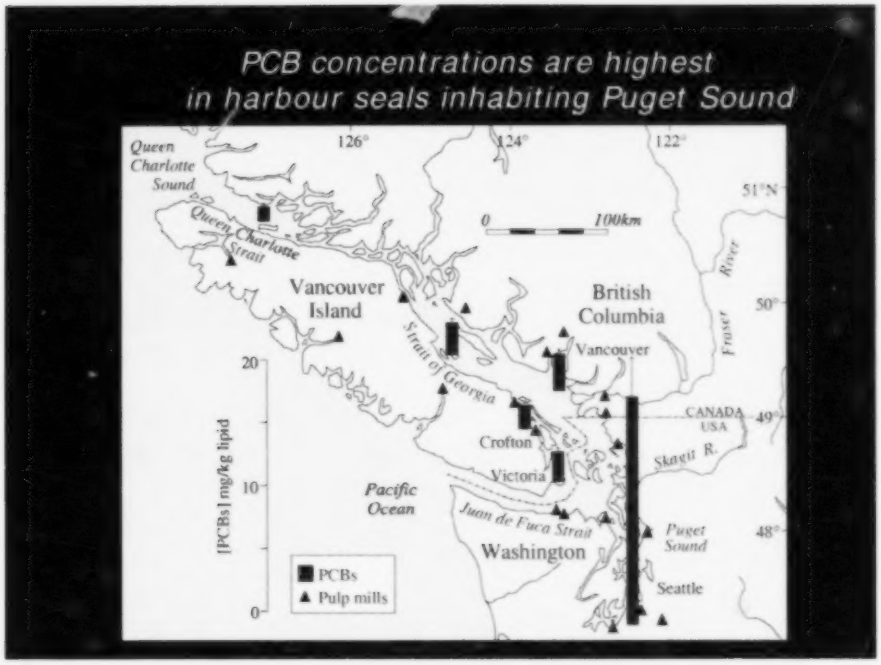


Figure 3. POPs (persistent organic pollutants) atmospheric transport



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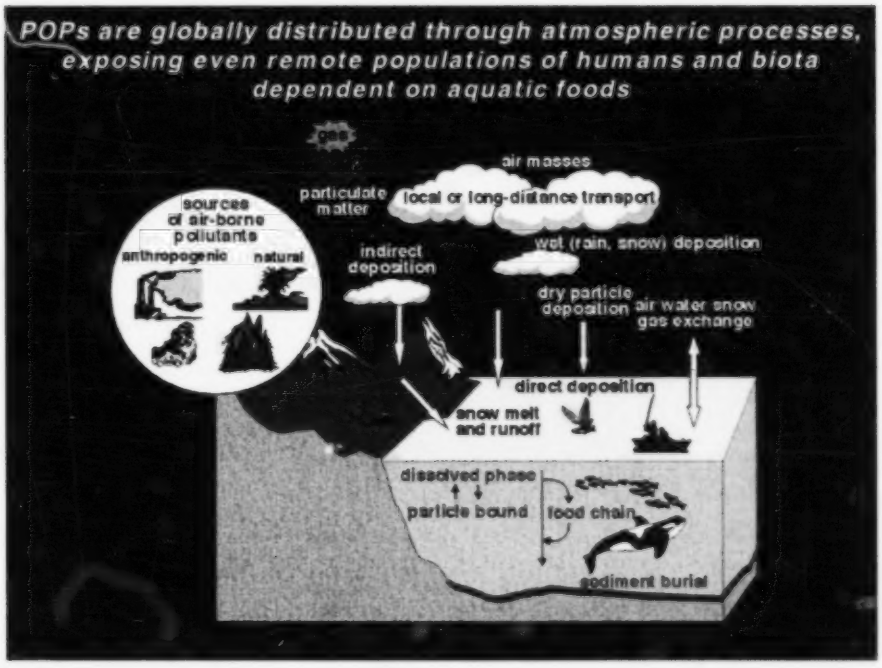

Figure 3. POPs (persistent organic pollutants) atmospheric transport

It is difficult to determine the effects of toxic chemicals on marine mammals. Legal, ethical and logistical considerations all conspire to challenge the very best science. However, we do know that complex environmental mixtures of toxic chemicals affect the immune and endocrine systems of harbour seals, and field studies suggest that such effects have led to reproductive impairment, increased incidence of disease, and developmental abnormalities in wild marine mammal populations in Europe and North America. Ultimately, a 'weight of evidence' is needed to assemble different pieces of evidence; such a combination entails the consideration of laboratory animal studies, captive feeding studies of marine mammals, and epidemiological studies of wild marine mammal populations.

Our results are published in international journals and are presented at scientific conferences. Such fora provide us with a rigorous peer assessment of our work, an essential foundation for subsequent outreach efforts including public lectures and media interviews. Our research findings provide a basis for an informed contribution to management, conservation, regulatory and mitigative strategies that help to ensure that our ocean remains healthy for all species. Steps taken to reduce or eliminate the inputs of toxic chemicals during the last 30 years have helped to protect aquatic wildlife; such steps have been taken as a result of solid scientific research and effective mitigative efforts by managers and by industry. Further steps at identifying new chemicals of concern are needed to ensure that marine mammals, including killer whales, thrive in British Columbia's coastal environment.

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CITIZEN SCIENCE: AN INCREDIBLE OPPORTUNITY OR A CRUEL OXYMORON?

Brian D. Smiley

Since 1996, Marine Environmental Habitat Science Division (MEHSD) scientists, biologists and youth interns have led in developing, testing and publishing the intertidal Shorekeepers Guide (Jamieson *et al.*, 1999) and subtidal Reefkeepers Guide (Conley *et al.*, 2001). These modular protocol guides, with their supporting training curriculum and databases, are practical protocols for non-professionals to map habitats and survey associated biota. Using these guides along with proper training and co-ordination, volunteers could be expected to produce data of sufficient quality for use by resource managers, environmental biologists and marine researchers in monitoring and assessing long-term changes in marine communities. The guides are patterned loosely after the DFO Streamkeepers Manual and the DFO Coastal and Estuarine Fish Habitat Description and Assessment Manual.

Our goal is to enable interested youths and adults to volunteer annually as individuals and groups in obtaining standardized, credible data from dozens of strategically selected coastal sites and to monitor the changes in marine communities over time in British Columbia. Based on scientific analyses of these data, we will be able to document and possibly explain the nature and extent of change, if any that is occurring. At the same time, the so-called 'citizen scientists' will become better informed about marine ecosystems and their human threats, and in turn grow more dedicated in responsible actions of coastal stewardship and marine conservation.

The Shorekeepers protocol uses both physical substrate (e.g. sand, mud, cobble) and biological features (e.g. rockweed and eelgrass beds) to define and map intertidal habitats of a 100m wide shore site at a very large scale of 1:300 (Table 1). The youth and adult teams, using temporary transects and quadrats for recording species diversity and abundance, also sample these habitats. The Reefkeepers protocol is somewhat more detailed, since recreational divers must observe the diversity and abundance of selected species of fish and invertebrate within a narrow swath or "tunnel" along a 30 m long permanent transect. Working together as paired buddies, the divers conduct one to three systematic passes of the transect, recording sightings on clipboards with water proof forms.

In actual field testing the protocols with representative groups, several hundred youth and adults were trained and co-ordinated by young biologists hired annually through the DFO Science and Technology Youth Internship Program, in partnership with private sector companies and non-government organizations (NGOs). Groups participating included displaced fishers, First Nations, high schools, environmental societies, dive clubs and others.

Consequently, 100+ Shorekeepers sites and one Reefkeeper site were surveyed annually and monthly, respectively, for one to four years largely on SE Vancouver Island. The youth interns and First Nation trainees also were tasked to verify and enter these data into custom database applications.

Attached Species Abundance

Study Area Name: Huddlestone Road
DFO Registration No: SK1997007
Survey Year: 1999

Habitat Type	Dominant Substrate	Species Common Name	Average % Cover	S.D.	Total Habitat Area (m²)	Estimated Cover (m²)	# of Obs.	S.D.
Cobble/Shell	Cobble	Brown Barnacle	2.1	5.1	1348	28.1	6	1.4
Cobble/Shell	Cobble	Pacific blue mussel	2.1	5.1	1348	28.1	6	1.4
ed or other macroalg	Bedrock	Black pine/Sea pine	14.6	12.3	2568	374.5	6	46.0
ed or other macroalg	Bedrock	Bladderwrack/Rockweed	2.1	5.1	2568	53.5	6	2.7
ed or other macroalg	Bedrock	Brown Barnacle	4.2	6.5	2568	107.0	6	6.9
ed or other macroalg	Bedrock	Common Barnacle	4.2	6.5	2568	107.0	6	6.9
ed or other macroalg	Bedrock	Eelgrass	4.2	6.5	2568	107.0	6	6.9
ed or other macroalg	Bedrock	Encrusting red	2.1	5.1	2568	53.5	6	2.7
ed or other macroalg	Bedrock	Gracilaria	10.4	5.1	2568	267.5	6	13.7
ed or other macroalg	Bedrock	Green Moss	6.3	6.8	2568	160.5	6	11.0
ed or other macroalg	Bedrock	Pacific blue mussel	2.1	5.1	2568	53.5	6	2.7
ed or other macroalg	Bedrock	Pacific Oyster	2.1	5.1	2568	53.5	6	2.7
ed or other macroalg	Bedrock	Red laver/nori/dulse	6.3	6.8	2568	160.5	6	11.0
ed or other macroalg	Bedrock	Red tufted algae	6.3	6.8	2568	160.5	6	11.0
ed or other macroalg	Bedrock	Sargassum /Japanese weed	18.8	15.3	2568	481.5	6	73.7
ed or other macroalg	Bedrock	Sea hair/Sea confetti	6.3	6.8	2568	160.5	6	11.0
ed or other macroalg	Bedrock	Sea lettuce	8.3	6.5	2568	214.0	6	13.8
ed or other macroalg	Bedrock	Sea Or Tan cauliflower	10.4	5.1	2568	267.5	6	13.7
ed or other macroalg	Bedrock	Turkish towel	6.3	6.8	2568	160.5	6	11.0
Sand (intertidal)	Sand	gregate Anemone/Green Anemon	6.3	6.8	710	44.4	6	3.0
Sand (intertidal)	Sand	Anemones	4.2	6.5	710	29.6	6	1.9

Table 1. Example of Shorekeepers Database Summary Report based on habitats mapped and intertidal organisms counted by volunteers in different habitats at one site on SE Vancouver Island.

Over the last two years, our challenge in MEHSD has been to evaluate the quality and utility of these archived data. Monies from the DFO Environmental Science Strategic Fund and other sources have allowed us to closely examine these datasets and to carry out preliminary analyses and interpretations. Results of these appraisals are now available (Jamieson *et al.*, 2002 and Burd *et al.*, 2001). Based on these findings and

recommendations, we have already taken steps to revise the field protocols, change data management procedures, improve co-ordination and training of volunteers — or we know how to, as and when these initiatives continue.

For example, Jamieson *et al.* (2002) found various degrees of inconsistencies and mistakes by Shorekeepers in executing 34 operational steps of field surveys, mapping habitats with spatial consistency, identifying plants and animals accurately, and transcribing between field sheets and computer spreadsheets without errors (Table 2). However, we concluded that none of these shortcomings were insurmountable, given the following:

- Shorekeeper data needs ongoing DFO verification and management by a designated Science Branch technician;
- The Shorekeepers' Guide should be considered a dynamic document, with ongoing modifications and revisions to address issues raised now and in the future;
- Involvement of resource, habitat and ocean managers is warranted to better assess the operational utility and application of these data; and
- Audits of survey team performance should become a routine part of the leadership-training program.

Year	N	Step 13 Identify habitats	Step 15 Locate baseline	Step 18 Calculate scale of sketchmap	Step 21 Calculate coordin-ates	Step 22 Measure area of habitat	Step23 Measure slope of habitat	Step 24 Measure elevation of habitat	Step 27 Lay out transects & quadrats	Step 31 Estimate abundance of biota
1997	33	20 (61%)	5 (5%)	3 (9%)	1 (3%)	7 (21%)	1 (3%)	10 (30%)	33(100%)	31(94%)
1998	28	16 (57%)	8 (7%)	3 (11%)	2 (7%)	2 (7%)	1 (4%)	13 (47%)	28(100%)	20(71%)
1999	48	28 (58%)	8 (7%)	1 (2%)	2 (4%)	8 (17%)	1 (2%)	17 (35%)	48(100%)	33(69%)
TOTAL	109	64 (59%)	21(19%)	7 (6%)	5 (5%)	17(16%)	3 (3%)	40 (37%)	109(100%)	84(77%)

Table 2. Number of Shorekeeper surveys in which a quantitative step was incorrectly done or reported by non-professionals and youth interns (%, with respect to totals). (Source: Jamieson et al., 2002)

Likewise, the Reefkeepers data evaluation by Burd *et al.* (2001) found bias and errors caused by inexperienced divers, mis-identification of species, inconsistent enumeration, oversight of cryptic animals, and variable conditions of visibility, current and algal cover (Figures 1 and 2). They recommended the following to address these weaknesses:

- Select taxa for observation that are reduced in number, easier to identify and are considered reef dwellers;
- Reduce diver bias by better post-dive debriefing, additional habitat information, more video records, and improved training; and
- Revise survey methods and training procedures to better ensure seasonal frequencies of surveys, pairing of experts with novices, comparison of disturbed habitats with controls, standard use of lights, estimates of percent cover for algae, and periodic re-testing.

Copper Rockfish

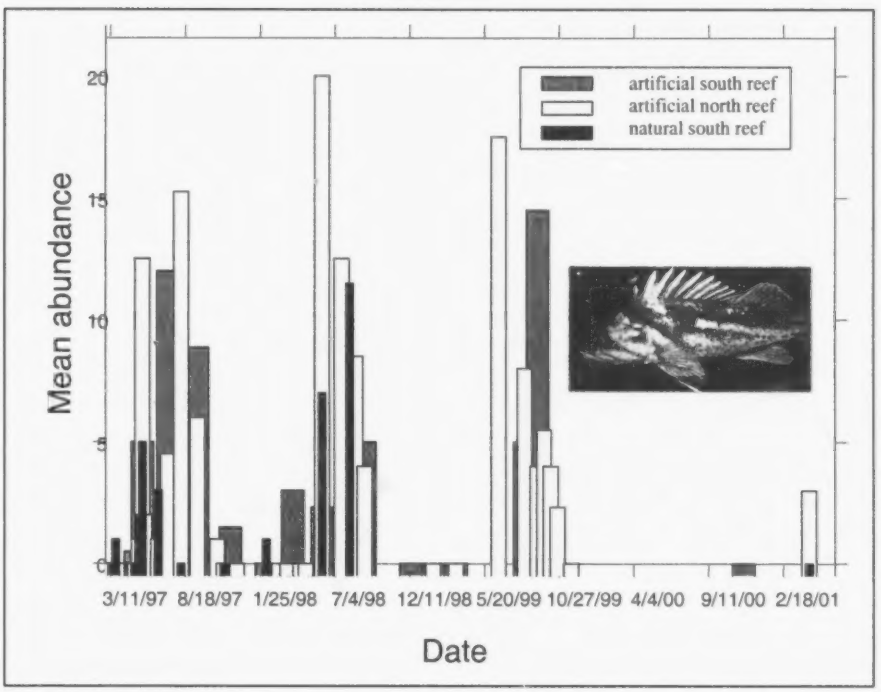

Figure 1. Abundance of copper rockfish (Sebastes caurinus) observed by volunteer Reefkeeper divers at SPARS Artificial South Reef, Artificial North Reef and Natural South Reef, Sidney, BC. 1997 – 2001. (Source: Burd et al., 2002).

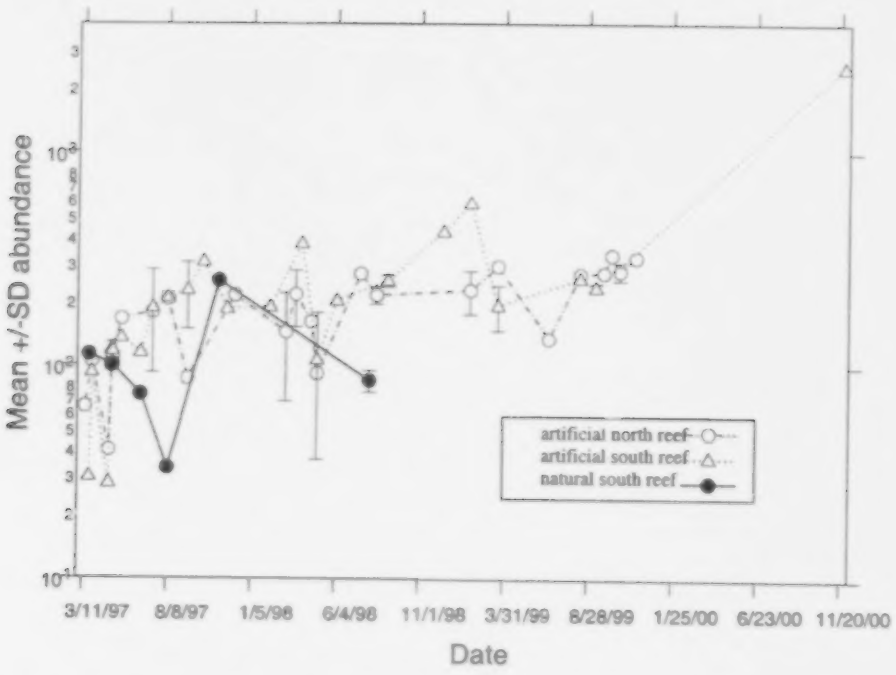

Figure 2. Mean abundance of all taxa observed by Reefkeeper volunteer divers on the SPARS Artificial Reef North, Artificial Reef South and Natural Reef South, Sidney, BC. 1997 to 2000 (Source: Burd et al., 2002).

So, how would we answer the question, is citizen science an opportunity or oxymoron? Volunteers can indeed produce defensible data, useful in providing better information and good advice to coastal managers and other decision-makers. This pertains not only to Reefkeepers and Shorekeepers, but also to others such as Streamkeepers, Straitkeepers, Living REEF Project and Great Canadian Beach Cleanup. However the volunteers must be provided practical protocols and effective data management systems (a lead role opportunity for Science Branch) AND they must be carefully recruited, adequately trained, well co-ordinated and motivated (a lead role opportunity for Oceans Directorate, Habitat and Enhancement Branch and others). If, because of difficulties in funding and staffing, this "and" is really an "or", then the citizen science endeavours will be fraught with unmet expectations, disappointment, frustration, apathy and eventual failure. This is especially hard on the volunteers.

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FRESHWATER HABITAT SECTION

PORT MOODY ARM, BURRARD INLET: THERMAL INPUT AND CONCERN FOR SALMON

Ian K. Birtwell and Jill S. Korstrom

Port Moody Arm (PMA), is situated at the eastern end of Burrard Inlet, B.C. The arm is 6.5 km long with a mean width of 0.9 km and a mean depth at low tide of 8.8 m. The arm also includes over 1 km^2 of natural mud flats which are exposed at low tide. Five small streams comprise the main freshwater input into the arm. Heat enters the arm from solar input and the daily discharge of up to 1.7 billion liters of cooling water at a temperature of 27 °C from BC Hydro's Burrard Electric Generating Station (BGS) which is situated on the PMA's north shore.

Federal and provincial agencies and public interest groups and municipalities expressed concern for the health of chum salmon (*Oncorhynchus keta*) because the temperature of the BGS cooling water exceeds the in lethal limit of 23.8 °C. MEHSD was requested by federal and provincial agencies and BC Hydro to investigate the potential impacts of discharge on juvenile chum salmon. The investigation was conducted from the West Vancouver Laboratory with funding provided by BC Hydro.

Laboratory experiments

The behavior of chum salmon was examined in isothermal (10 °C) and thermally stratified (24 °C/10 °C) seawater (with and without food). In the absence of food, the juvenile salmon occupied the waters close to the water surface and only moved from this preferred location as temperatures increased.

The responses of the fish were defined as "attraction" (50% response 12.2 °C), "preference" (>80% response 13.7 °C to 20.2 °C) or "avoidance" (50 % response 20.2 °C) levels.

The salmon rapidly and briefly entered potentially lethal temperature waters (25 °C and 30 °C) to feed: the obviously protective and adaptive avoidance responses to these temperatures were temporarily overridden by the presence of food and the motivation to feed.

Field experimentation

The vertical distribution of chum salmon was determined in PMA. Fewer fish were present in the waters closest (70 m) to the thermal discharge. The chum salmon tended to

occupy their preferred surface water habitats in which temperatures occasionally exceeded optimal values. It was concluded that the BGS thermal discharge did not significantly affect the vertical distribution of juvenile chum salmon.

Consequences to juvenile chum salmon of exposure to warm seawater

Juvenile chum salmon were given a sublethal exposure to a combination of elevated temperature and dissolved gas supersaturation (which occurs in cooling waters). Their subsequent survival was assessed through their susceptibility to predation from rockfish, kelp greenling and sculpin.

These experiments revealed an overall enhanced vulnerability of juvenile chum salmon to predation. Possibly due to the debilitating effects of elevated temperatures and / or elevated dissolved gases on swim performance and an associated reduced ability to recover from fatigue brought on by predator attacks and the need for repetitive escape responses.

Risk of harm to juvenile salmon upon exposure to BGS cooling water

Numbers of juvenile chum salmon typically decline in near shore coastal areas during late spring and early summer. At this time, surface water temperatures and dissolved gases in PMA tend to increase to levels that, in combination, could lead to an increased vulnerability of juvenile chum salmon to predation, reduced growth rates and condition.

However, the rapid removal of >80% of the heat entering the arm through tidal action limits elevation of temperature above seasonal ambient levels. Accordingly, temperatures (and total gas pressure) rarely attain levels that would be harmful to chum salmon during the time of year that they reside in PMA.

We concluded that the current discharge of cooling water from the BGS will not adversely affect chum salmon populations that utilize PMA.

The findings were presented to BC Hydro, governments, and public interest groups, and provided the basis for reduced concern over the thermal discharge into PMA.

THE EKATI DIAMOND MINE: LITIGATION AND PROVISION OF ADVICE

Ian K. Birtwell

Discovery of diamonds in the Northwest Territories resulted in an expansion of exploration and mining in the 1990's. The lakes in this region are nutrient-poor, food-limited and pristine, typically a few meters deep, and covered by 1-3 m of ice for up to 8 months a year. The lakes are considered to reflect a biological "climax" condition with a delicate ecological balance. These lakes often have a few dominant fish species (e.g. lake trout) that are very old and large, but slow growing. Kimberlite pipes contain the diamonds and are like "volcanic carrots" emanating from the Earth's deeper layers frequently surfacing at a lake bottom.

In the early 1990's BHP Billiton Diamonds Inc., (BHP) commenced development of the Ekati mine 350 km north of Yellowknife. Development of the Koala and Panda pits resulted in removal of fish and fish habitat. Subsequently, BHP was to compensate DFO for the loss of fish habitat.

In the late 1990's (1997 to 1999) sewage from the mine was added to Kodiak Lake, resulting in a stimulation of plant growth and increased food for those higher in the food chain. Unfortunately a continuing depression of dissolved oxygen occurred (primarily during winter); levels stressful or lethal to fish.

In order to conduct mining operations and to permit fish passage in the 185,000 km^2 Koala watershed, drainage water was diverted. This was accomplished over 3 winters (1994-1996) by blasting a 3 km-long channel [the Panda Diversion Channel (PDC)] through permafrost and granite. Armoring the sides of the PDC was an important requirement to prevent erosion of silt-rich permafrost and soils. DFO stipulated the importance of preserving aquatic habitat and its quality, yet recognized a likely initial transient increase in turbidity from the PDC waters once it became operational. The waters of the PDC exit into Kodiak Lake, then to Little, and Moose Lakes and a series of other lakes until emptying into Lac de Gras (a large lake with a recognized fishery).

The clarity of the previously pristine waters in the lakes close to the Ekati mine was influenced by development as early as 1994. By 1995 turbid water was flowing into Kodiak Lake. In 1997 the PDC was fully operational. However, a portion of the PDC was inadequately armored and resulted in an estimated 17,944 cubic meters of sediment being eroded, a portion of which entered the first lake, Kodiak Lake, during the first freshet (typically late May and June). Concentrations of suspended sediment in PDC waters were 484 mg/L (June 2), 355 mg/L (June 16), 83 mg/L (July 2), 47 mg/L (July 14), and 6 mg/L (August 1). Sediment concentrations in waters entering the PDC during the same time period were <5 mg/L.

The sediment input resulted in a significant deposition within Kodiak Lake. Estimates ranged from 13.9% of the lake bottom covered by sediments greater than 1 cm in thickness (close to the PDC to >1 m depth), to 66.6% covered by more than 0.1 cm (sediment deposition of 1-4 mm has been shown to kill fish eggs).

DFO (Central and Arctic Region) charged BHP under the Fisheries Act for the deposition of a deleterious substance (i.e. sediment), and the harmful destruction and alteration of fish habitat. BHP contested the charges, and asserted that the habitat provisions of the Fisheries Act should not apply to the lakes in their claim because there was not an existing or expectation of a potential fishery, and that they had been duly diligent in dealing with the problems encountered.

The matter was heard in Supreme Court in Yellowknife, in 2002. The judge accepted that the BHP had deposited a deleterious substance into waters frequented by fish and that this had also resulted in the harmful alteration, disruption and destruction of habitat (HADD), both of which are offences under the Fisheries Act. The judge also confirmed that the provisions within the Fisheries Act were for the overall benefit of aquatic resources and not just those which comprised "fisheries" as was argued by the diamond mining company. Despite these conclusions the judge found the company not guilty of the charges laid because they had exercised due diligence to avoid the excessive deposit of sediment into the lakes downstream of the water diversion channel (the excessive sediment transport was not "reasonably foreseeable"), and that the HADD had been authorized by Fisheries and Oceans Canada.

YUKON PLACER AUTHORIZATION AND CURRENT RESEARCH ON THE EFFECTS OF SEDIMENT ON CHINOOK SALMON

Ian K. Birtwell and Jill S. Korstrom

Placer gold mining in the Yukon Territory is permitted under an Authorization of the Fisheries Act [Yukon Placer Authorization (YPA)]. The YPA permits mining to occur and also seeks to provide levels of protection for certain fishery resources. Since the late 1890's, there has been a significant change to fish habitat as a consequence of placer mining. These effects can be long lasting in the cold northern climates of the Yukon and Alaska.

Sediment is released into waterways as a consequence of most placer mining operations. Sediment has, and often is, discharged at concentrations harmful or lethal to fish [tens, to tens of thousands, of milligrams of sediment per liter (mg/L) water]. For example, concentrations as low as 10's of mg/L have been documented to impair fish feeding and migration, and kill the sac fry of Arctic grayling.
The YPA has undergone review in the expectation of benefiting from new information, as well as changing opinions and industrial practices. To assist in the review process research has been carried out to provide information on the effects of sedimentation on Yukon fish and their habitat.

Studies by DFO and others in the early 1980's focussed on the effects of mining on Arctic grayling; more recently studies have focussed on juvenile chinook salmon. Industry, governments, First Nations, and public interest groups have assessed applicability of the results of our research during their 2002 review of the YPA. The information has also been used in expert testimony during federal prosecutions under the Fisheries Act.

Brief preliminary findings on the effects of sediment on juvenile chinook salmon are given below.

Growth, over 3 weeks, of juvenile chinook salmon were adversely affected by sediment concentrations to which they were exposed (100, 300, and 1,000 mg/L). Relative to control, fish exposed to 1,000 mg/L suspended sediment grew 21% less. Those exposed to 300 and 100 mg/L grew 8.1% and 1.9% less, respectively.

Feeding of juvenile chinook on surface prey was impaired when exposed to all sediment concentrations tested (100, 300, and 1,000 mg/L), relative to controls in clear water (Figure 1). Effects were greater after 9-weeks exposure than after 3-weeks exposure to suspended sediment. After 3-weeks exposure fish in 100 mg/L and 1,000 mg/L had a 60.4% and 95.6% decrease in feeding efficiency, respectively. After 9-weeks exposure the corresponding decrease for 100 mg/L and 1,000 mg/L sediment-exposed fish was 87.5% and 98.3%.

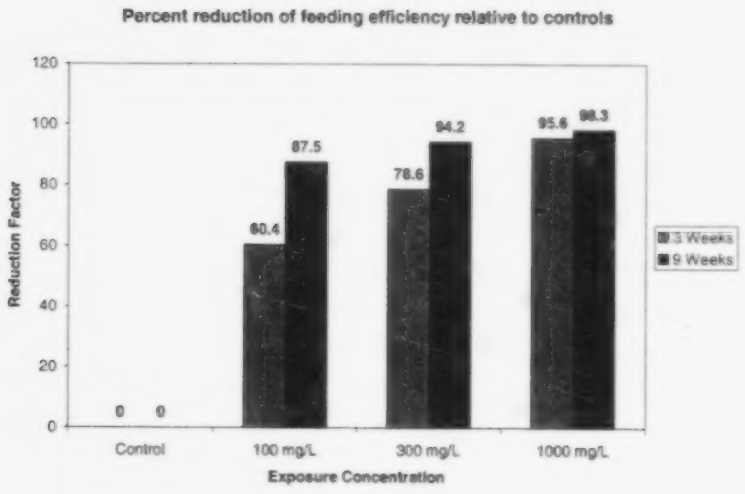


Figure 1. Percent reduction of feeding efficiency relative to controls.

Juvenile chinooks were more susceptible (5%) to predation by burbot following exposure to 30 000 mg/L suspended sediment for 47 h (predicted to be equivalent in effect to 9-weeks exposure to 1 000 mg/L). Fish subjected to this same treatment, had a reduced fright response (a natural escape response to seek cover) relative to controls. Also, more fish from the treated group failed to seek cover and more were immobile (indicative of acute stress). Such changes in behavior have been correlated with an increased susceptibility to predation.

The combination of these findings suggest that over time fish exposed to concentrations of suspended sediment equal to or greater than 1 000 mg/L for 9 weeks (as may occur in placer mined streams) would be harmed and their life compromised.

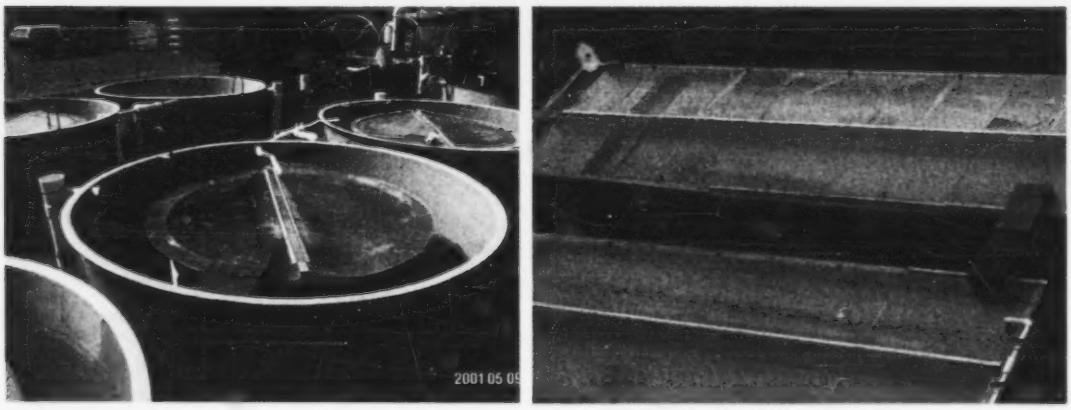
Exposure to lower levels of suspended sediment is expected to impair the feeding and growth of juvenile chinook salmon; the magnitude of the effect being related to the availability of prey. Because elevated levels of suspended sediment have been shown to adversely impact prey items for these fish it is highly probable that the diminished feeding efficiency of fish in turbid waters will, when combined with impoverished food resources, have a greater negative effect on growth, and hence survival. These effects would likely be manifested at sediment concentrations much less than 100 mg/L.

THE EFFECT OF UV RADIATION ON THE PHYSIOLOGICAL CONDITION AND GROWTH OF JUVENILE COHO

Max Bothwell, Blair Holtby, Kevin Nickolichuk and Michael Arts

Research has shown that natural levels of solar ultraviolet radiation (UVR) can have negative effects on both algae and insects living in shallow freshwater with potential indirect impacts on stream-rearing salmonids. In laboratory settings, UVR has also been shown to have direct effects on fish. High intensity UVR from artificial lamps can cause sunburn and cataracts. A collaborative research program between Fisheries and Oceans and Environment Canada has been investigating the potential for UVR to have both direct and indirect effects on juvenile coho. Juvenile coho are susceptible to UVR because they rear in shallow streams and removal of riparian vegetation cover following logging has been shown to dramatically increase exposure to UVR. Even coho reared in outdoor hatchery tanks are potentially vulnerable to UVR.

Juvenile coho are reared in outdoor stream mesocosms containing natural river food web communities and in hatchery tanks with food rations (Figures 1 to 5). Coho have been exposed to three photo environments; 1) visible light only (PAR), 2) PAR plus longwave UV (UVA) and 3) full-spectrum sunlight including shortwave UV (UVB). Fish grown under these three light conditions have been compared in both natural and hatchery settings. While neither the lipid content nor the total amount of somatic fatty acids (FA) was affected by photo treatments, the condition factor of the coho suggested that they do best when exposed to PAR+UVA. A shift in the FA composition under UVR also indicated a positive effect of UVA compared to UVB or to no UV at all. Two fatty acids, arachidonic acid (AA) and eicosapentaenoic acid (EPA) were affected by UVR. Changes in the ratio of AA:EPA indicated the fish were under stress when exposed to PAR+UVA+UVB and PAR alone, but not under PAR+UVA.



Figures 1 and 2. Hatchery tanks at Rosewall Creek for rearing juvenile coho in the presence and absence of natural solar ultraviolet radiation.

Figure 3. Under cloudy skies coho actively forage in mesocosm pools.

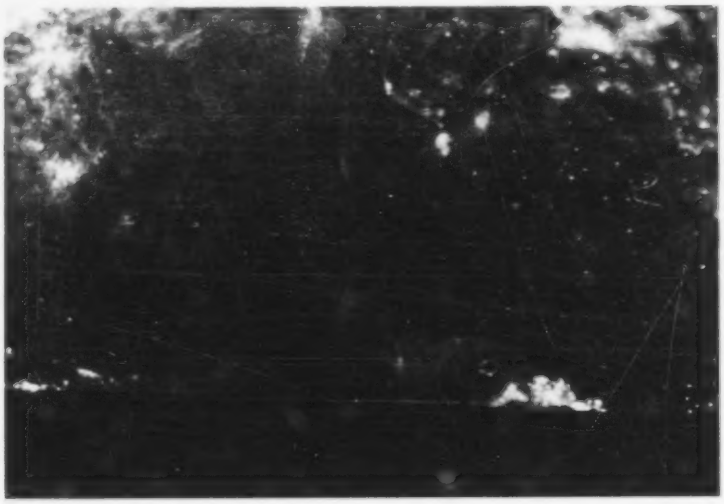


Figure 4. Under sunny skies coho seek shelter from UVA under rocks in the pools.

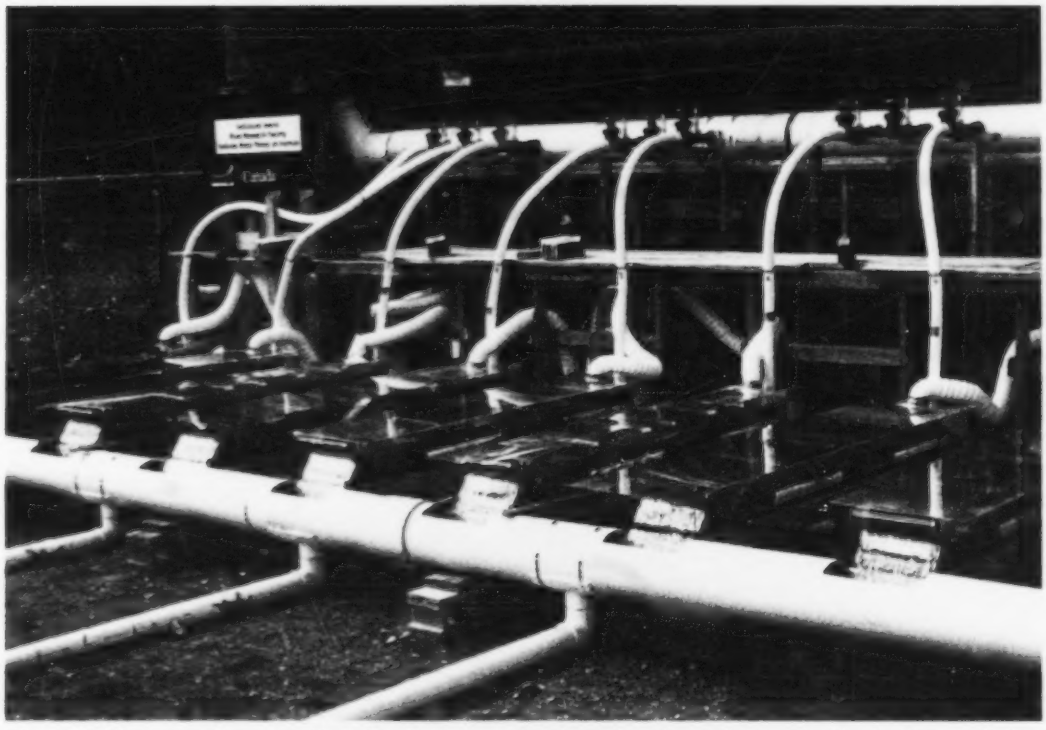


Figure 5. Mesocosm flumes at Little Qualicum exposing juvenile coho and the entire foodweb to sunlight with and without UVA and UVB radiation.

Additional parameters of juvenile coho being investigated in response to UVR exposure are: body morphology and swimming characteristics; blood plasma thyroxin, cortisol, sodium and potassium levels; and the degree of fin erosion.

Behavioral experiments have also shown that juvenile coho avoid higher levels of ultraviolet radiation. Avoidance of UVA is most pronounced.

USE OF SHUSWAP LAKE FORESHORE BY JUVENILE SALMONIDS

Tom G. Brown and Paul Winchell

The foreshores (littoral zone) of large lakes such as Shuswap Lake are under considerable pressure from urbanization. Many beaches are naturally sandy (Figure 1), but cobble and boulder substrates cover many of the foreshore beaches (Figure 2). Cobble substrate is removed for private beach creation and collected in rows (Figure 3), riparian vegetation is cut, protective walls are built, emergent vegetation is removed, and small marshy bays are altered. We studied the littoral zone associated with the main arm of Shuswap Lake for 3 years with field-work conducted during the spring and summer months (April to August). This study was designed to define the role of Shuswap Lake's littoral zone as salmonid fish habitat and to assess the potential impacts of foreshore development.

Figure 1. Sandy-gravel beach, Shuswap Lake

Figure 2. Cobble beach, Shuswap Lake

Figure 3. Foreshore development, man-rowing of boulders.

Shuswap Lake is located in the interior of British Columbia. This lake is an important source of Thompson River sockeye (*Oncorhyncus nerka*), chinook (*O. tshawytscha*) and coho (*O. kisutch*) salmon. Lake levels annually rise from 3 to 4 m, and are associated largely with snowmelt (Kramer 2002). Interior lakes, such as Shuswap Lake, have their lowest lake levels in March (March 22/2001 at 344.8 m elevation) and highest levels in June or July (June 14, 1972 at 349.66 m elevation). These annual rises flood a considerable portion of the lake margins and occasionally inundate surrounding riparian vegetation i.e. 1997 and 1999 (Kramer 2002). The largest single daily increase in lake level was 24 cm (May 28/1972; Kramer 2002). From April to June, juvenile salmonids can exploit previously dry lake margins as the water levels rise. Fish can access alcoves, channels, and bordering wetlands previously isolated from the lake.

Juvenile chinook, coho and sockeye utilize the foreshore areas of Shuswap Lake for rearing and migration (Fedorenko and Pearce 1982; Graham and Russell 1979; Russell *et al.*, 1980). Our attempts to capture fish by minnow trapping proved ineffective. We used a beach seine to capture juvenile salmonids during daylight in 1999 from sandy and cobble beaches. Juvenile chinook were more numerous on sandy beaches than on cobble beaches (Anova; $P<.05$) (Figure 4). Chinook juveniles were found most often on exposed sandy beaches, as were the few sockeye juveniles captured. Coho juveniles were limited in distribution. Coho fry were found within flooded backwater areas and not on exposed beaches. The highest densities of juvenile coho were associated with a backwater channel near the Adams River.

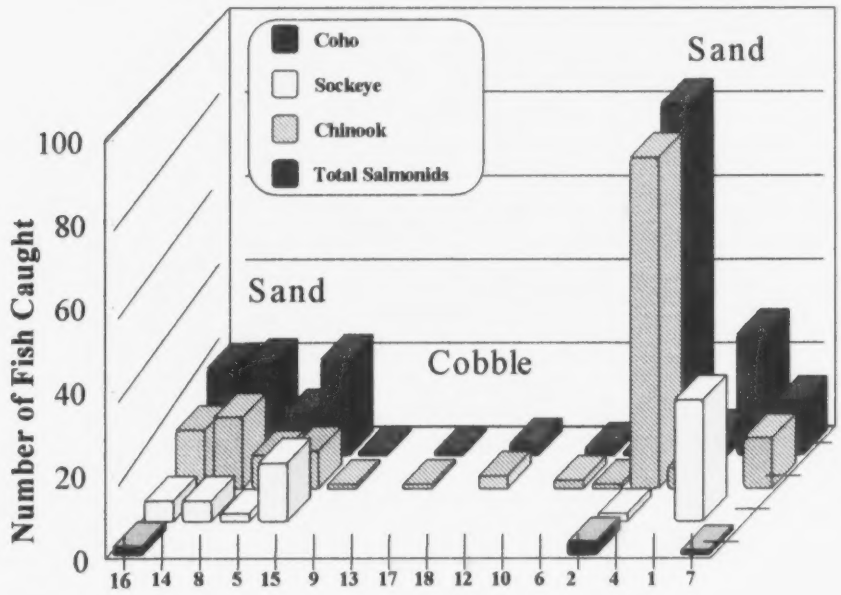


Figure 4. Comparison of catches on 8 sandy and 8 cobble beaches. Total salmonid catch was significantly greater on sandy beaches.

Juvenile chinook salmon fry were captured by pole-seine along the shallow flooded margins (< 1m depth) of Shuswap Lake in spring 2000 and 2001. Juvenile chinook used the littoral zone from March 28 to July 10. This estimate is slightly earlier and longer than the duration of foreshore use given by Russell *et al.*, 1980 (April 25 to July 6). Their capture success along the lake margins declined rapidly in July. Graham and Russell (1979) documented a similar disappearance of juvenile chinook from the margins of Shuswap Lake in July.

These lake rearing chinook juveniles exhibited a strong nocturnal behaviour as night catches were 20-30 times greater than day catches (Figure 5).

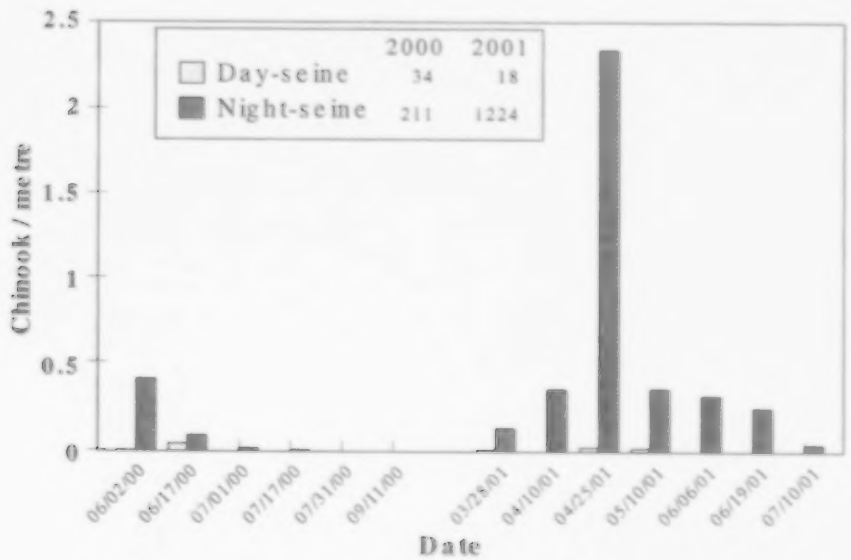


Figure 5. Juvenile chinook density was highest in late April and lake margin use was strongly nocturnal.

Night-time fishing using a 2-person pole-seine, 3m in width, was highly effective in catching juvenile salmonids. Juvenile salmon catches at night in late April were 2.4 fish/m of shore (Figure 5). At night juvenile chinook densities were greatest within the first ½ meter of foreshore (Figure 6).

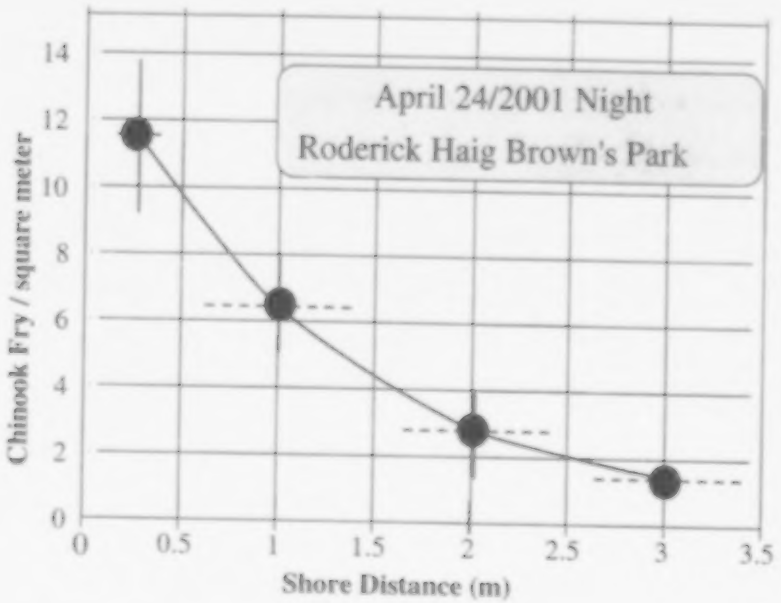


Figure 6. At night juvenile chinook were closely associated with the shallow (< 10 cm) lake margins.

Four possible reasons for this strong nocturnal behaviour can be hypothesized; predation avoidance, more acceptable water temperatures, no UV radiation, and increased feeding opportunities on the flooded, shallow, lake edges. The relationship between water temperature, beach slope and the processing of terrestrial litter input is a critical feature of the littoral zone. Surface water temperatures indicate that shallow beaches have warmer edges and are more likely to process litter in early spring.

Invertebrates that land on the lake surface become a source of food for juvenile fish. We compared the relative inputs of insects from cleared open riparian shores with treed shores by using water traps (Figure 7; aluminium trays filled with water, a small quantity of detergent, and a drop of formalin). Four traps were used at each open (Figure 8) and treed site (paired design). A greater number of insects were captured from the open lakeshores than from the treed shores (Figure 9; paired-t-test; $P > .001$). This difference can be attributed to the larger input of flying aquatic insects associated with the open beaches (Figure 10). The input of terrestrial invertebrates was similar for treed and open shores.

Figure 7. Insect water traps (aluminum trays filled with water and a drop of detergent) were used to sample insect input to the lake surface.

Figure 8. Along an open beach (no trees), 4 insect traps on stands were used to measure terrestrial and flying insect drop onto the lake surface.

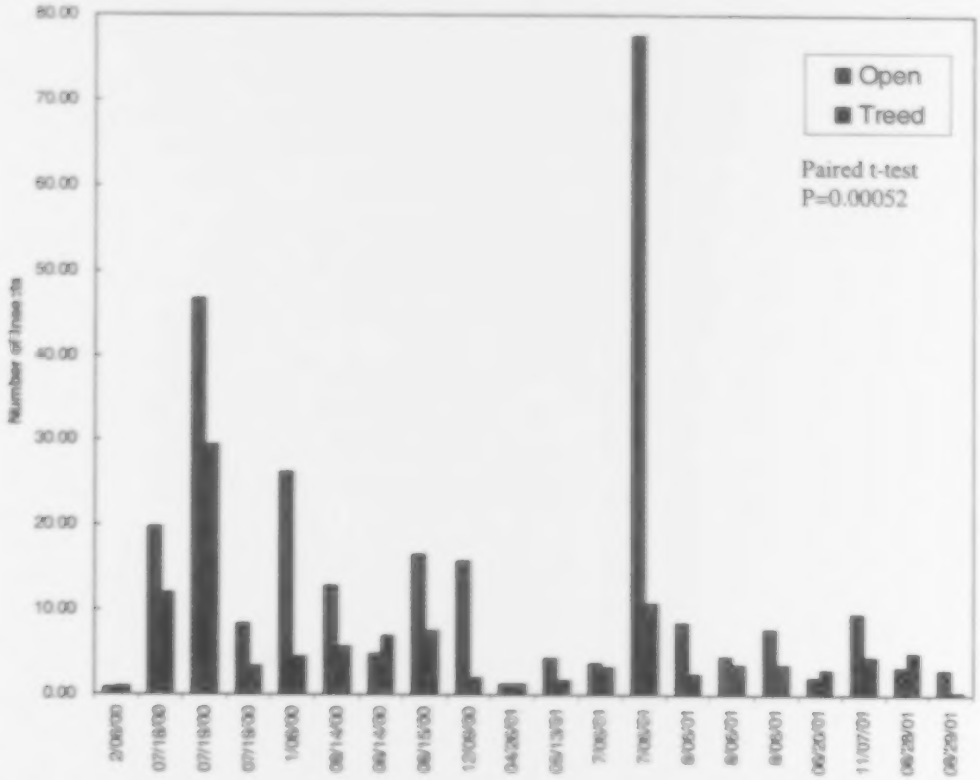


Figure 9. Comparison of treed and open beaches. Significantly more insects were captured from open areas.

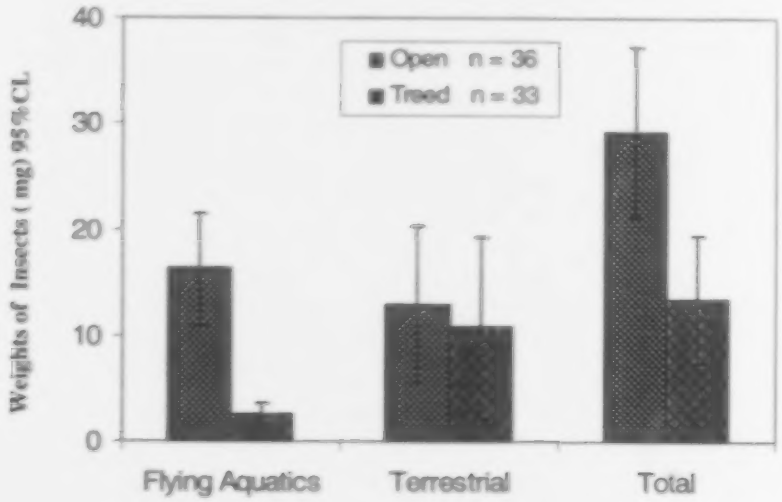


Figure 10. Difference in total weight of insects in traps was attributed to difference in flying aquatics and not to terrestrial insects.

Fish also feed on benthic invertebrates. Attempts to measure the types and production levels associated with different substrates were not successful during the first two years. The majority of substrate baskets and the invertebrates that had colonized them (Figure 11), were never recovered. A benthic sampler that used a bilge pump to suck invertebrates from the shallow lake foreshore was used during the last year of study (Figure 12). It is anticipated that this new method will provide a better estimate of benthic productivity.

Figure 11. Benthic substrate baskets were used with limited success.

Figure 12. Benthic sampler using bilge pump to suck up invertebrates.

The feeding habitats of juvenile salmon were examined through analysis of fish stomach contents. The degree of flooding may influence the type of food items available to juvenile salmonids. In June of 1999, 2000, and 2001 chinook salmon were captured along the shore of Shuswap Lake. Fish samples collected in 2001 have yet to be analyzed. The fish were seined from < 1.5m in depth. In 1999 the lake levels rose into the riparian zone flooding campsites and a few beach cabins. When the riparian vegetation was flooded; terrestrial items comprised (by weight) 14.6%, small larval fish [likely cottidae (sculpin) species] represented 20.3%, and benthic items consisted of 42.4% of the diet (Figure 13). In 2000, lake-levels rose up the beaches, but did not flood into the shore vegetation. In that year when only the unconsolidated shore was covered with water, 9.4 % of the chinook diet was terrestrial, 10.3% was flying aquatic insects, and no small fish were found, and 73.1% of the diet was benthic (Figure 14).

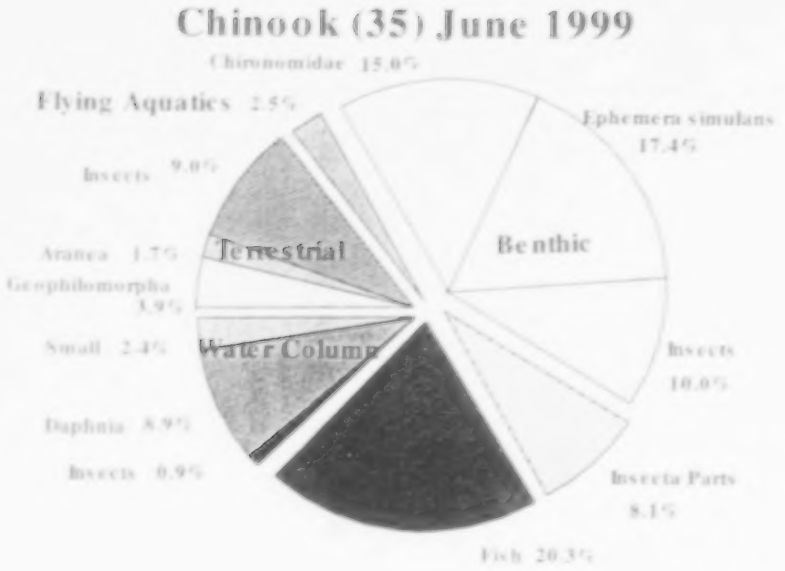


Figure 13. Chinook stomach contents, relative weights of major groups. Chinook captured by beach-seine and pole seine 1999.

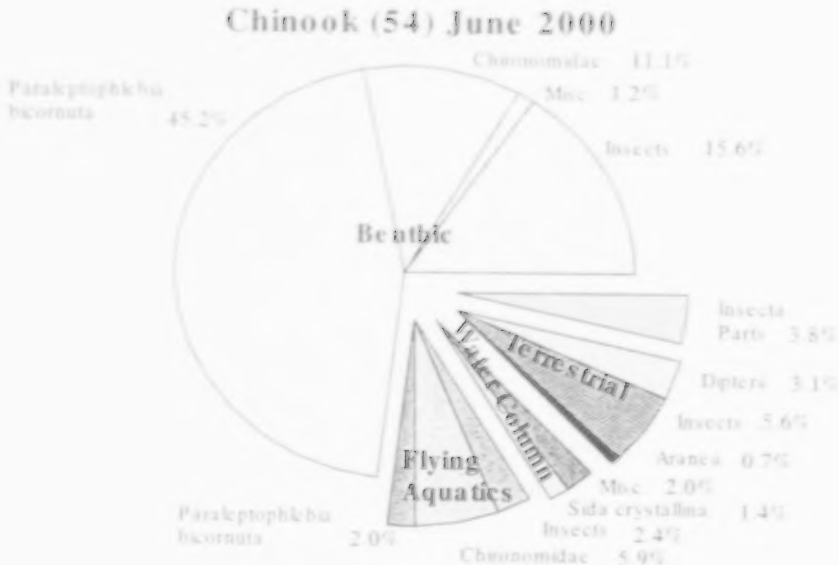
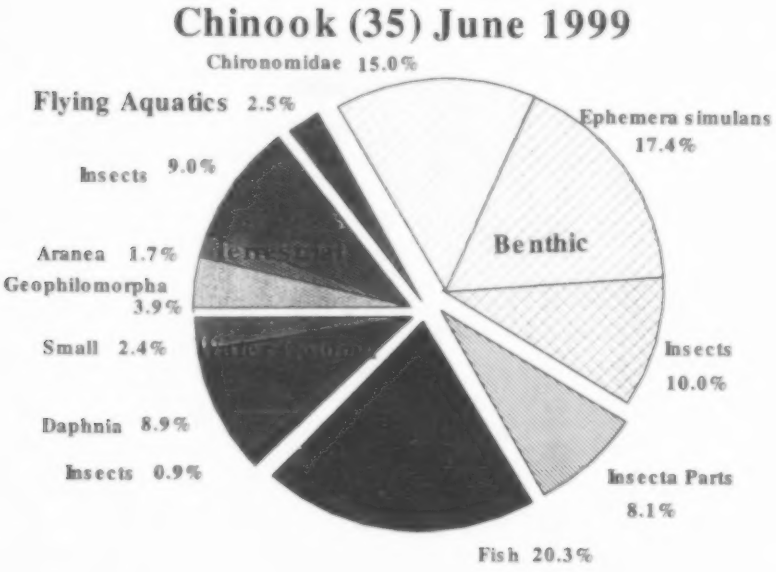


Figure 14. Chinook stomach contents, relative weights of major groups. Chinook captured by pole seine 2000.

The invertebrate groupings eaten by juvenile chinook can be described in greater detail. For example, the benthic organisms consumed by juvenile chinook in June 1999 (Figure 15) were dominated by midge (Chironomidae, Orthocladinae and Corynoneura) and mayfly larvae (*Ephemeroptera* and *Ephemera simulans*). In June 2000 (Figure 16),



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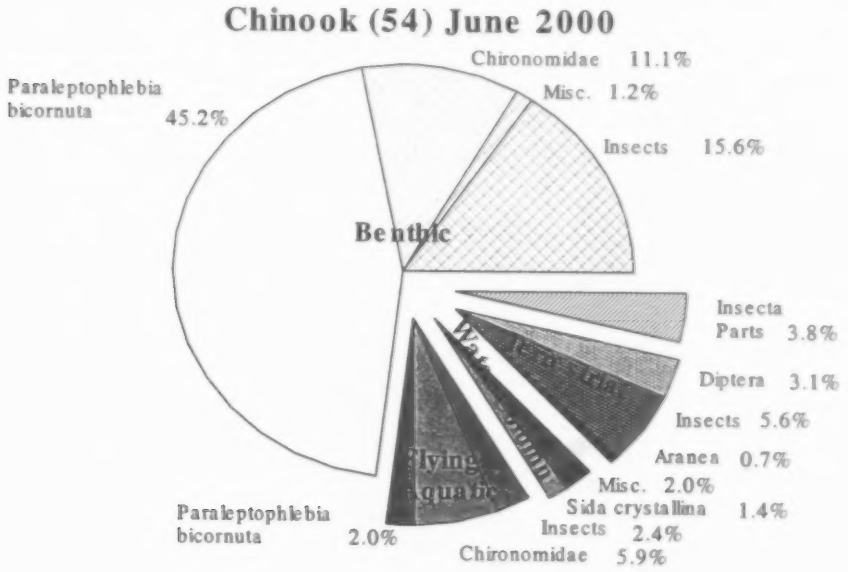

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midge larvae (Chironomidae, Orthocladinae, and Chironomini) were again dominant. However a benthic diptern (Bezzia) and two different mayfly species (*Paraleptophlebia bicomuta* and *Ephemerella inermis*) were common.

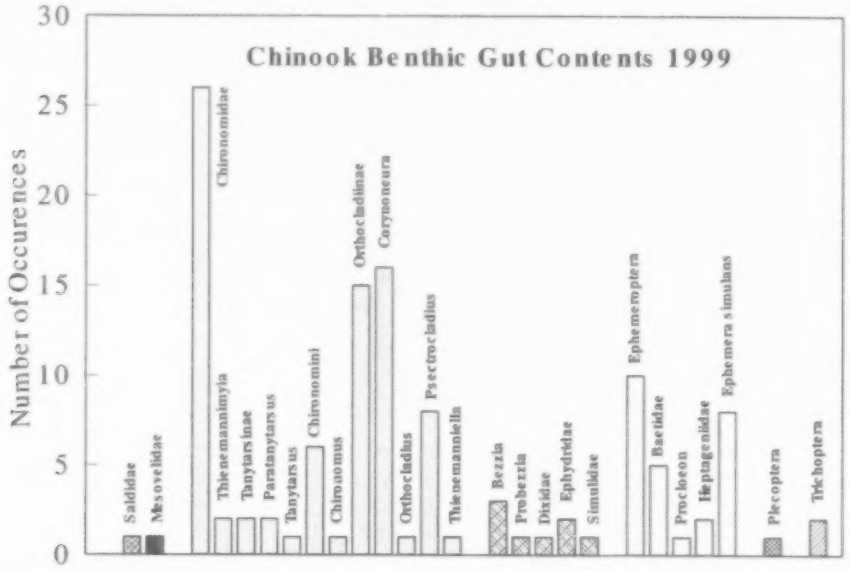

Figure 15. Benthic invertebrates (number of occurrences) identified in chinook stomachs taken in 1999.

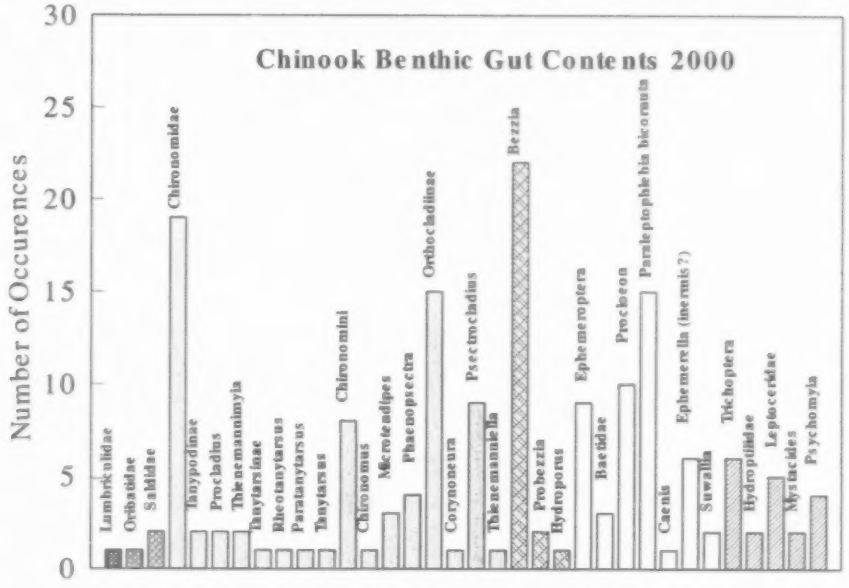

Figure 16. Benthic invertebrates (number of occurrences) identified in chinook stomachs taken in 2000.

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THE BIOLOGY OF CHINOOK SALMON IN THE YUKON RIVER BASIN AND THE 2002 YUKON PLACER AUTHORIZATION REVIEW

Mike Bradford

The Yukon Placer Authorization (YPA) of 1993 regulates the conduct of placer gold mining around rivers and streams of the Yukon Territory. In anticipation of a mandated 2001 review of the Authorization, research was initiated in 1997 on some of the underlying assumptions that were made during the development of the original Authorization.

The goal of the project was to describe the importance of small streams as rearing habitat for chinook salmon, and to provide a detailed description of habitat structure and fish use in these streams. The study was motivated by the 'deferment' clause of the YPA, which allows relaxation of sediment discharge standards in salmon-rearing streams based on the assumption that there was abundant and even excess habitat for salmon within the Yukon basin. The YPA assumes that overall productive capacity would not be impacted by deferring water quality standards in some streams.

A detailed study was conducted on a small stream near Whitehorse (Bradford *et al.*, 2001) that identified the seasonal and spatial patterns of habitat use by juvenile chinook salmon, and demonstrated the importance of small pools as preferred habitat within the stream (Figure 1). The stream produced yearly smolts, although ice conditions were an important factor on overwinter survival. We extended our surveys to other regions in the upper Yukon River basin and found that overwintering salmon were only present in the southern region where milder climate and the underlying glacial deposits permit adequate winter flows.

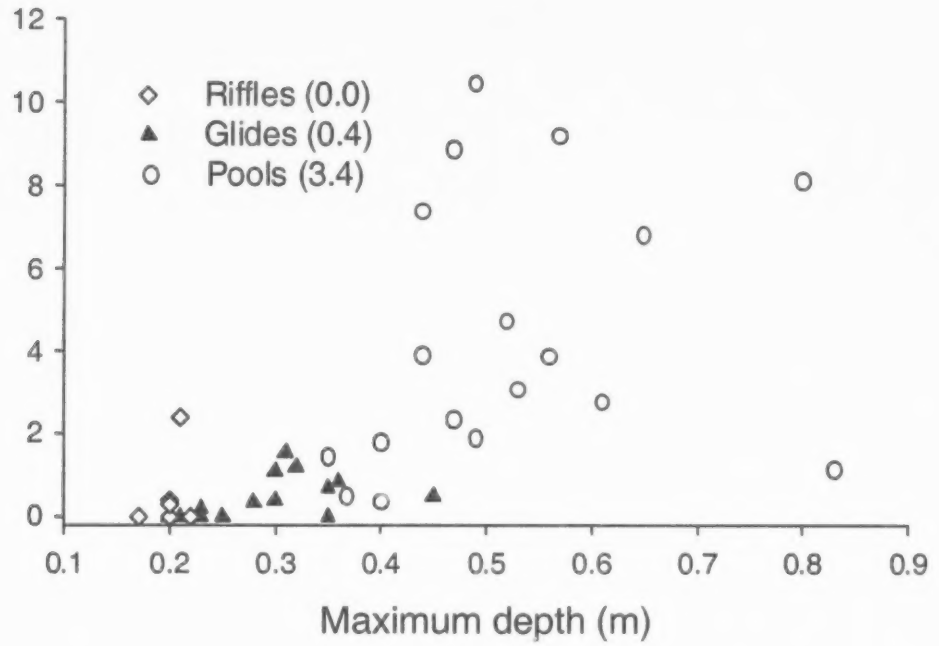

Figure 1. Densities of juvenile chinook salmon by habitat unit estimated by diver in Croucher Creek, near Whitehorse in 1998 as a function of the maximum depth of the habitat unit. Data are sorted by habitat type, with the median densities indicated. From Bradford et al., (2001).

The densities of juvenile chinook salmon in small streams were estimated in over a dozen streams between 1997 and 2002 to determine how well these streams were utilized at current levels of escapement. Reach-average densities of over 1 fish per metre^2 were consistently observed in streams with good habitat, and local densities exceeded 10 fish per metre^2. These observations do not support the assumption of the YPA that there is excess habitat in the Yukon basin at current levels of spawner abundance.

Low levels of sediment that are not toxic to fish can produce adverse effects on stream ecosystems and could ultimately affect the health of fish populations. One of these effects is the reduction in primary productivity (mainly periphyton) resulting from the attenuation of light by suspended sediment. This could impact fish populations if a significant portion of their diet were invertebrates that consumed stream algae. Russell Perry (SFU graduate student) used stable isotopes of carbon and nitrogen to estimate the proportion of growth of juvenile chinook salmon that resulted from instream algae relative to terrestrial leaf litter and found it to be correlated with suspended sediment levels in the stream (Figure 2)(Perry *et al.*, 2003). In streams with little suspended sediment a substantial proportion of the diet of fish and invertebrates resulted from periphyton production.

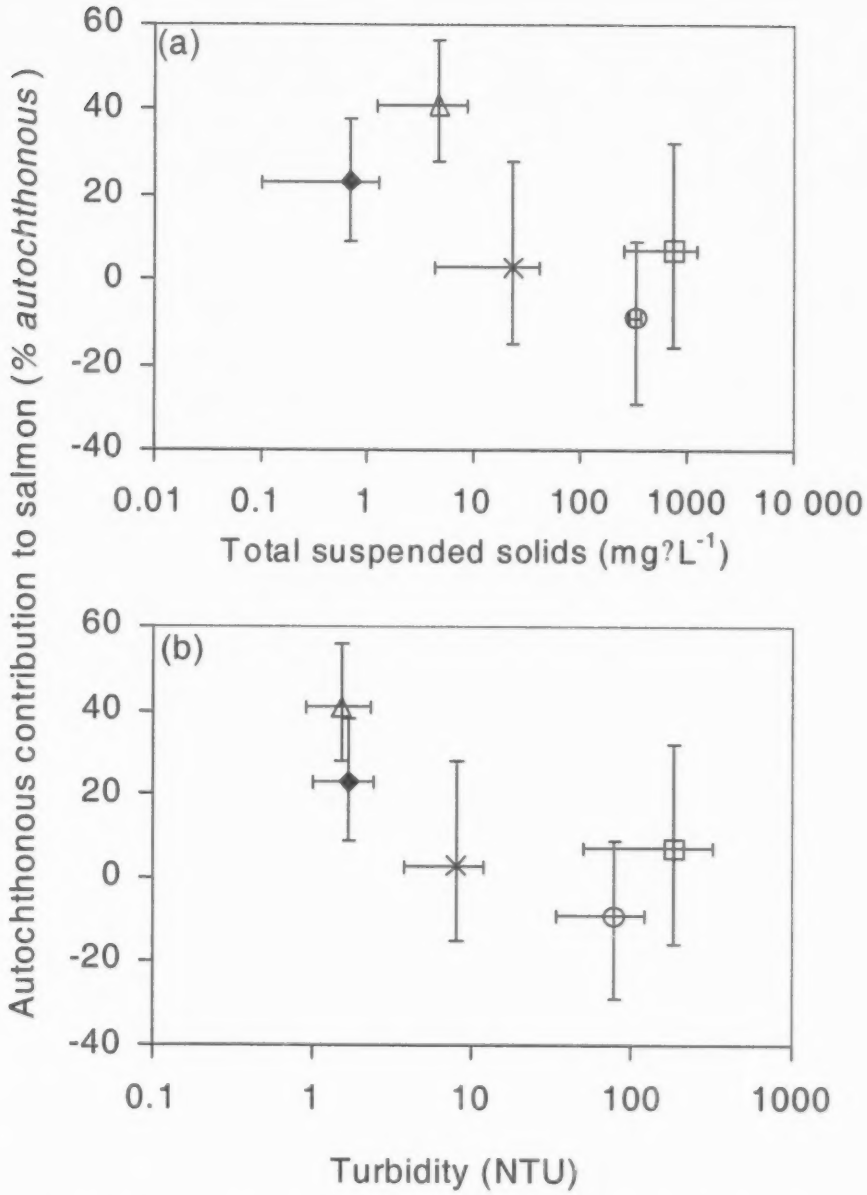

Figure 2. Relation between the proportion of juvenile chinook salmon growth resulting from autotrophic production (i.e. stream algae) and the average suspended sediment levels, July-August 2000 for 5 small streams that are tributary of the Yukon River near Dawson City YT. From Perry et al., (2003).

Placer mining can change the physical structure of small streams, and often surrounding riparian vegetation is completely removed. Brent Mossop (SFU graduate student, thesis in progress) evaluated the importance of woody debris to stream habitat in 12 small streams of the Yukon Basin. He found that woody debris was important to the creation of pools and cover, as has been found in more southerly locations, but the size of trees was

small. The age of trees large enough to be able to contribute to stream habitat was >80 years. These results indicate that the recovery of the streams from active placer mining may be a very slow process in northern latitudes.

The results from this study were presented in February 2002 to the Yukon Placer Committee during their review, and formed part of the information used by the Minister for his December 2002 decision to rescind the Authorization and develop a new regulatory regime for placer mining.

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PARTITIONING OF LIMNETIC FISH STOCKS IN SOCKEYE REARING LAKES

Jeremy Hume and Steve MacLellan

The Lakes Program conducts ecosystem research to investigate the productive capacities of sockeye salmon (*Oncorhynchus nerka*) nursery lakes by determining their trophic status, and the factors limiting lake productivity. Our work determines whether a sockeye stock is at or below the rearing capacity of its nursery lake. The findings are then used in predictive models to provide estimates of optimum escapements and to determine stocks at risk.

Sockeye are not the only species occupying the limnetic zone (open water) of lakes and feeding on zooplankton. Other fish may be in direct competition with juvenile age-0 sockeye, due to niche overlap in space, time and diet. In order to make more precise estimates of sockeye rearing capacity, this competition needs to be accounted for in the analysis and modelling of the juvenile sockeye community.

While freshwater communities can contain a complex mix of competitors, limnetic (open water) communities in BC sockeye lakes (such as Quesnel, and Shuswap) often consist almost entirely of various forms of *O. nerka*. Anadromous (ocean-going) sockeye, may comprise over 95% of the limnetic population, but the landlocked form, kokanee, may also be present in significant numbers. Sockeye usually rear in a lake for 1 year before migrating to the ocean in the spring of the following year. Kokanee never leave the lake and up to four age classes may be resident at any one time. These two forms of *O. nerka* are very difficult to visually distinguish in their first year (age-0). Other lakes may have a more diverse limnetic community, for example Harrison and Pitt lakes also contain longfin smelt and threespine stickleback, while Cultus Lake also contains threespine stickleback, pygmy sculpin, and redside shiner.

We use a variety of methods to determine the stock composition of the limnetic fish species. Density, abundance, and distribution of the limnetic fish are determined by conducting hydroacoustic surveys with a scientific echosounder. At night, the juvenile sockeye are found in the limnetic zone (open water) of their nursery lake where they are susceptible to acoustics and trawling (Figure 1). The echo sounder allows us to determine fish biomass and abundance along pre-determined transects in a lake. The target strength of the echo detected from individual fish enables us to distinguish small fish (<150mm) from larger ones. Samples collected with a midwater trawl provide detailed information on size as well as species composition, and in addition, material for further analyses such as scale and otoliths. It is the combination of these methods that allows us to estimate sockeye populations and to produce a detailed partitioning of the limnetic fish community.

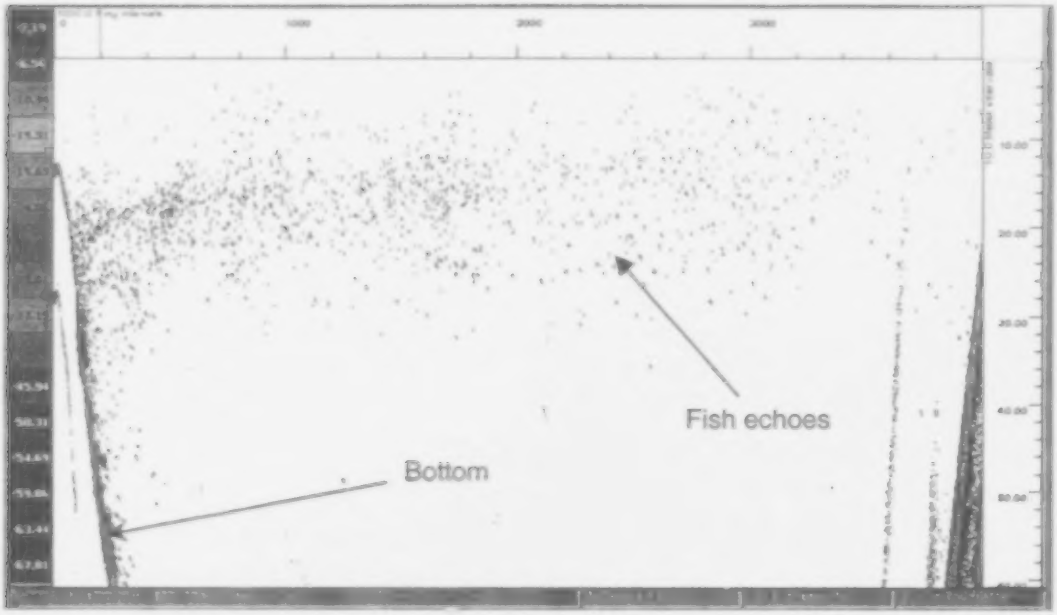

Figure 1. An echogram of a transect across Quesnel Lake showing the bottom and fish echoes.

A survey conducted on Quesnel Lake in September 2000 illustrates the process of determining a population estimate and partitioning it into the various competitors and ages. We collected hydroacoustic data along a series of transects across the lake (Figure 2) and derived a population estimate for each transect. The population estimate for each transect was then summed to provide a total population estimate of 15.0 million fish in the limnetic zone of the lake (Table 1). Acoustic target strength information identified 1.2 million of these as large fish.

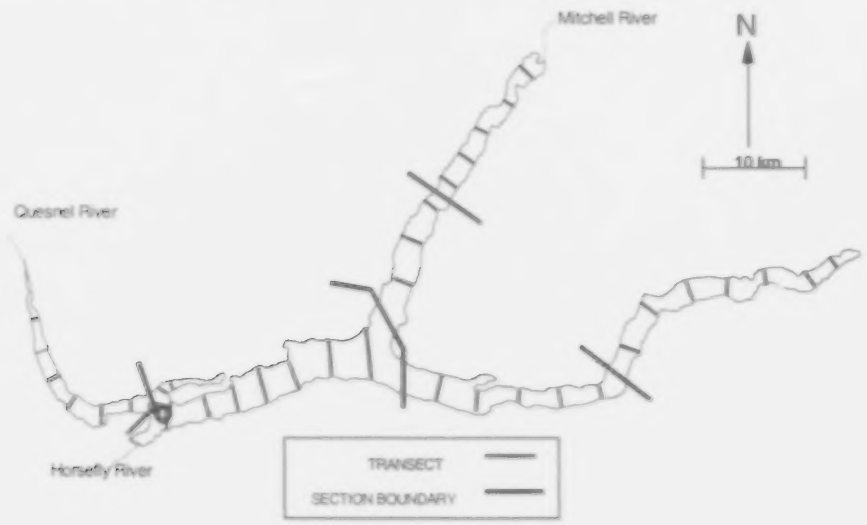

Figure. 2. Quesnel Lake showing the hydroacoustic transects and trawling sections.

Method	Stock Group	Abundance (Millions)
1.	Acoustics - Echo integration	
	All limnetic fish	15.0
2.	Target Strength	
	Small fish (<150mm)	13.8
	Large fish (>150mm)	1.2
3.	Trawl catch and scale ages	
	Age-0 *O. nerka*	9.7
	Age-1 *O. nerka*	4.1
	Age-2+older *O. nerka*	1.2
4.	Otolith Core Sr content	
	Age-0 Sockeye	7.9
	Age-0 Kokanee	1.8
	Age-1 Sockeye	0.2
	Age-1 Kokanee	3.9
	Age-2+older Kokanee	1.2

Table 1. Results of applying successive analytical steps to the hydroacoustic population estimate of Quesnel lake O. nerka . 1) the initial hydroacoustic estimate of limnetic fish, 2) division into large and small fish target strength, 3) division into species and age based on trawl catch and scale aging, 4) division into sockeye and kokanee based on the Sr content of the otolith cores.

Fish samples were also taken from 6 sections of the lake using a midwater trawl (Figure 3). These fish were then identified and processed using a number of methods. All fish in the trawl catches were identified as some form of O. *nerka*. The fish were then aged using the annual growth rings found on the scales in addition to length frequency analysis. It was determined that all of the larger fish were age 2 or older, while 70% of the smaller fish were age-0 and the rest were age-1.

Figure 3. Launching the midwater trawl from the deck of the Night Echo.

The identification of the offspring was also determined through the analysis of the otolith bone, a small bone in the ear of a fish that grows with the fish. The otolith core is formed before hatching and is exclusively derived from maternal biomass. It contains trace elements reflecting the maternal rearing environment.

Concentrations of strontium (Sr) in the ocean are a 100 times higher than in most lakes and it's concentration in the otolith core of an O. *nerka* fry can distinguish the maternal rearing conditions. High levels of Sr indicate the offspring of sockeye while low levels indicate the offspring of kokanee (Figure 4). From this analysis we estimated sockeye comprised 82%, 4% and 0% of the age-0 , age-1 and older O. *nerka* respectively (Figure 5 and Table 1). Using a variety of sampling methods and a series of analytical steps we were able to determine the species and age structure of the midwater fish population of Quesnel Lake.

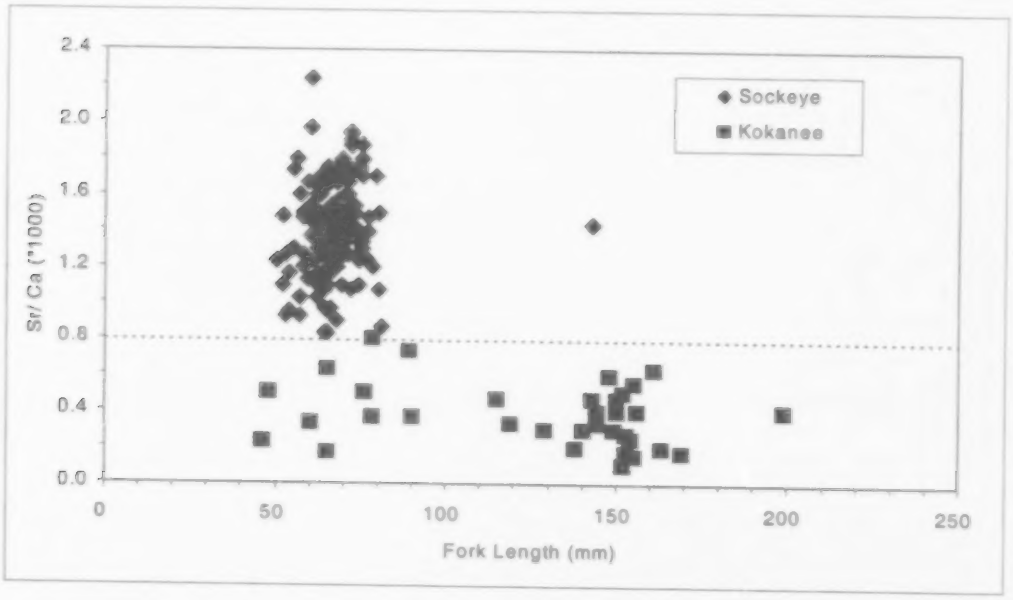

Figure. 4. The ratio of Strontium to calcium in the core of O. nerka otoliths (ear bones) captured in Quesnel Lake. Values above 0.8 indicate the otoliths are from the offspring of sockeye while values below 0.8 indicate the offspring of kokanee.

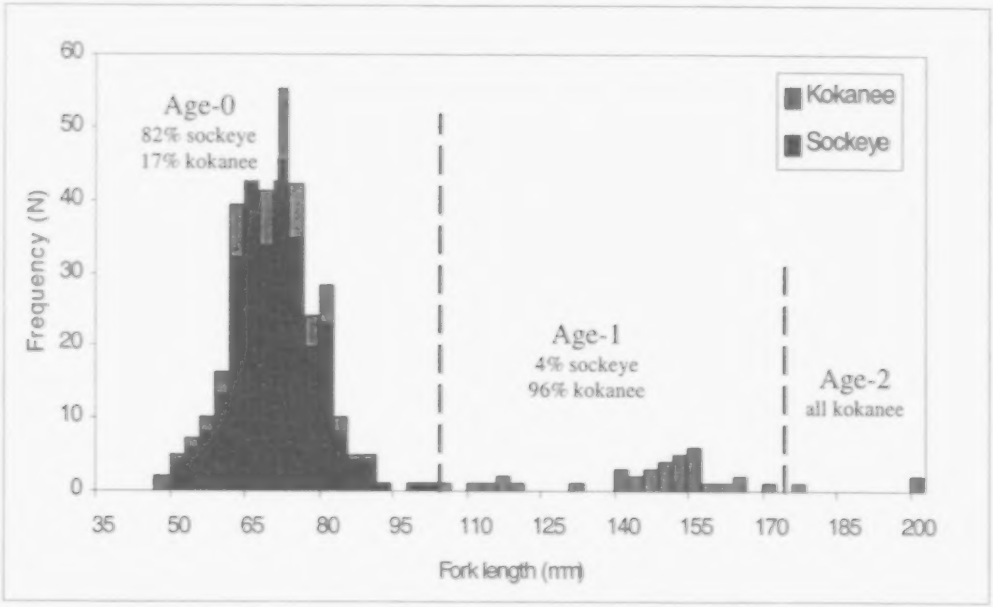

Figure 5. Results of the length frequency, scale ageing and otolith core analysis showing the estimated proportions of sockeye and kokanee by age class for O. nerka caught in Quesnel Lake.

EN ROUTE LOSS DURING SOCKEYE SPAWNING MIGRATIONS: THE INFLUENCE OF UNFAVOURABLE ENVIRONMENTAL CONDITIONS IN THE FRASER RIVER

J. Stevenson Macdonald, Ian Guthrie and David Patterson

Introduction

Programs to investigate the influence of environmental conditions in the Fraser River on sockeye salmon (*Oncorhynchus nerka*) spawning migrations have been in existence for over 30 years. Two recent reviews, the Pearce-Larkin Report (1992) and the Fraser Report (1995) have provided the impetus to consider this issue a priority. The theme central to 30 years of investigations, is the belief that a link exists between the spawning success of stocks of Fraser River salmon and the water temperatures and river discharge experienced by the fish along the migration path. Most vulnerable are Fraser sockeye returning in June, July and August including the Early Stuart, Early Summer and Summer stock groups, but late groups are also likely influenced by severe river conditions. In recent years late-run stocks have exhibited extraordinarily high levels of mortality in association with early river entry and upstream migration. Stock productivity has been threatened, rebuilding initiatives delayed, and in-season fishery management is exceedingly difficult.

The purpose of this project is to identify those environmental conditions that have influenced the migration success of four run-timing groups of sockeye salmon in the Fraser River from 1977 to the present, thus providing insight into the root causes of en route loss. Environmental variables such as river discharge and temperature have been collected in the lower river since 1912 and 1941, respectively. Using these variables, we propose a method to adjust lower-river spawning escapement targets to account for the losses associated with extreme environmental events and abnormal migration timing. A general linear model (GLM) is created to predict the difference between lower-river and upper-river estimates of escapement based on water temperature, discharge abundance and timing data. During the fishing season, "environmental management adjustment" (EMA) estimates are produced from the model, based on forecasts of river conditions, that maximize the likelihood of achieving spawning escapement targets. The proposed method will increase the chance of achieving escapement targets when migration conditions are difficult.

Methods

The response variable in the model describes the difference between lower-river (LoRiv) and upper-river (UpRiv) estimates of spawning escapement and is expressed as the natural logarithm of the ratio between these estimates. Thus:

$$Y = \ln(LoRiv) - \ln(UpRiv) = \ln(\frac{LoRiv}{UpRiv}) = a + b_1 X_1 + b_2 X_{2+...}$$

where a, b1 and b2 represent the regression parameters, and X1 and X2 represent environmental predictor variables. Alternatively, the exponent of the response variable equals the ratio between the lower-river and upper-river estimates.

$$\exp(Y) = \frac{LoRiv}{UpRiv}$$

This is a convenient and intuitive way of expressing the difference between estimates. An exp(Y) value of 1 means the estimates are the same, while a value greater than 1 means the abundance estimate in the lower-river was larger than the upper-river estimate.

The result can be expressed as a rate that can be applied to the spawning escapement target (SET- at Mission), after the addition of the anticipated catches in recreational and native fisheries (the gross escapement), to predict the numerical difference between upper and lower-river estimates and to estimate the necessary management adjustment. To calculate the size of the management adjustment (EMA) in fish units, the calculation would be:

$$EMA = SET * (\exp(Y) - 1)$$

Results and Discussion

Basing the management of Fraser River sockeye on relationships between estimates at Mission and spawning ground escapement is merited, considering the strong relationship between these estimates for each of the four run-timing groups (Figure 1). For the Summer and Late sockeye runs, differences between the estimates fall on both sides of the 1:1 line, which suggests that Mission and spawning escapement estimates, are relatively unbiased and most natural and fishery-induced mortality in the river can be explained within the normal variation associated with the estimation methods. For Early Stuart and Early Summer groups, however, the lower-river estimates tend to be higher than the upriver estimates. Significant to our analysis is that during years when river temperatures or discharges are unfavourable (Figure 1), lower-river escapement estimates exceed spawning ground estimates, suggesting the occurrence of en route loss in the river. Furthermore, during each run-timing period there was significant statistical power among the environmental and timing variables (transformed to principle component scores) to predict the differences between abundance at Mission and the spawning grounds (response variable, Y)($p<0.05$).

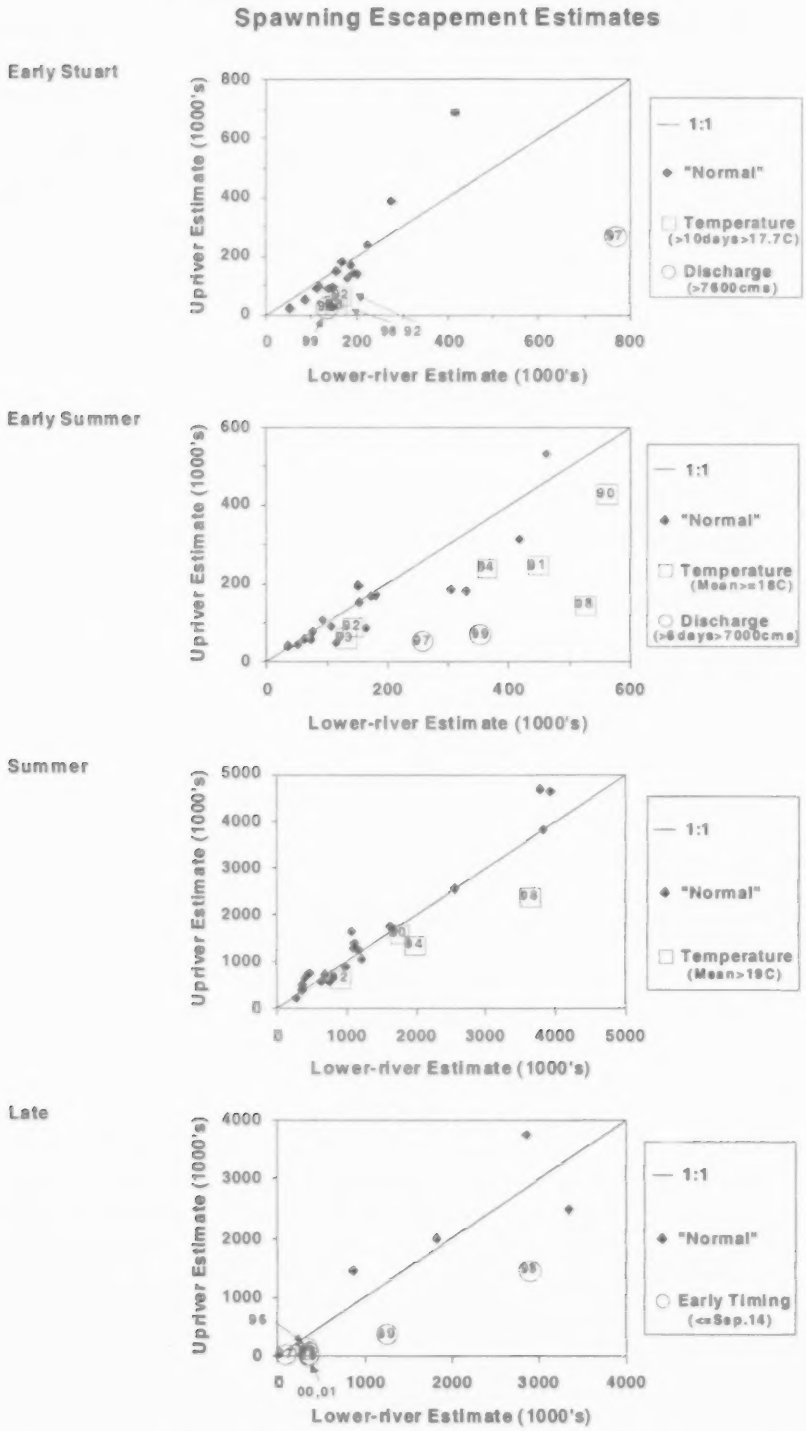

Figure 1. Comparison of lower-river (in-season) and upriver (post-season) estimates of spawning escapement for each run-timing group, showing years of extreme temperature or discharge for early and summer stocks, and 50% migration date at Mission for the Late run (excluding Birkenhead).

The ratio of differences between the Summer and Late-run groups is predicted best using single predictor models (Table 1). The Summer-run model indicates that high water temperature can impede Summer-run migration. Early entry to the Fraser system of Late-run sockeye is clearly the variable driving their en route losses ($p<0.0001$, Table 1) and provides the best predictive model among all of the run-timing groups ($r2= 92.2\%$). High water temperature to a greater degree than high discharge has more influence on the differences in estimates since 1977 for the Early Stuart group, but both are required to optimise our prediction (Table 1). Similarly, difference in estimates for the Early Summer group is best modelled with two predictor variables (discharge and temperature), but the discharge component (particularly Q>7000cms, PCII) has the greatest value as a predictor (Tables 1).

Variables		Parameter Values			Model Performance		
i 1	i 2	a	i 1	i 2	Adj. R^2	Prob.	RMSE
Early Stuart							
#days T>17.7°C	Mean Discharge	-1.2677	0.1171	2.81E-04	46.0%	0.0021	0.4534
Early Summer							
#days Q>7000cms	Mean Temperature	-2.8384	0.1605	0.1756	53.3%	<0.0001	0.3521
#days Q>7000cms	#days T>17.7°C		0.1519	0.0290	*a*	<0.0001	0.3514
Summer							
#days T>18.8°C		-0.1185	0.0235		26.0%	0.0054	0.2227
Mean Temperature		-2.3832	0.1329		21.1%	0.0122	0.2300
Late-Lates							
50% Mission Date		19.431	-0.0735		92.2%	<0.0001	0.3130

a Adjusted R^2 not directly comparable to results from models with intercept.

Table 1. Selection of the "best" models for each run-timing group, showing the predictor variables, parameter estimates and performance measures. (RMSE = root mean square error).

Comparisons of actual lower-river escapement estimates with estimates that have been modified by the EMA models, to account for the influence of migration conditions, show a great deal of agreement with the 1:1 line (Figure 2). The application of the EMA to lower-river escapement targets improved the likelihood of achieving spawning escapement targets for each run-timing group. This would particularly be true for years with extreme migration conditions (high discharge or temperature); when lower-river escapement estimates alone underestimate the spawning ground estimates (Figure 1). The environmental management adjustment provides a simple and reliable method to incorporate the environmental conditions along the migration pathway into Fraser sockeye management protocols. Therefore, our ability to monitor and forecast these conditions in conjunction with accurate stock strength estimates is fundamental to our ability to improve methods by which we manage Fraser River sockeye.

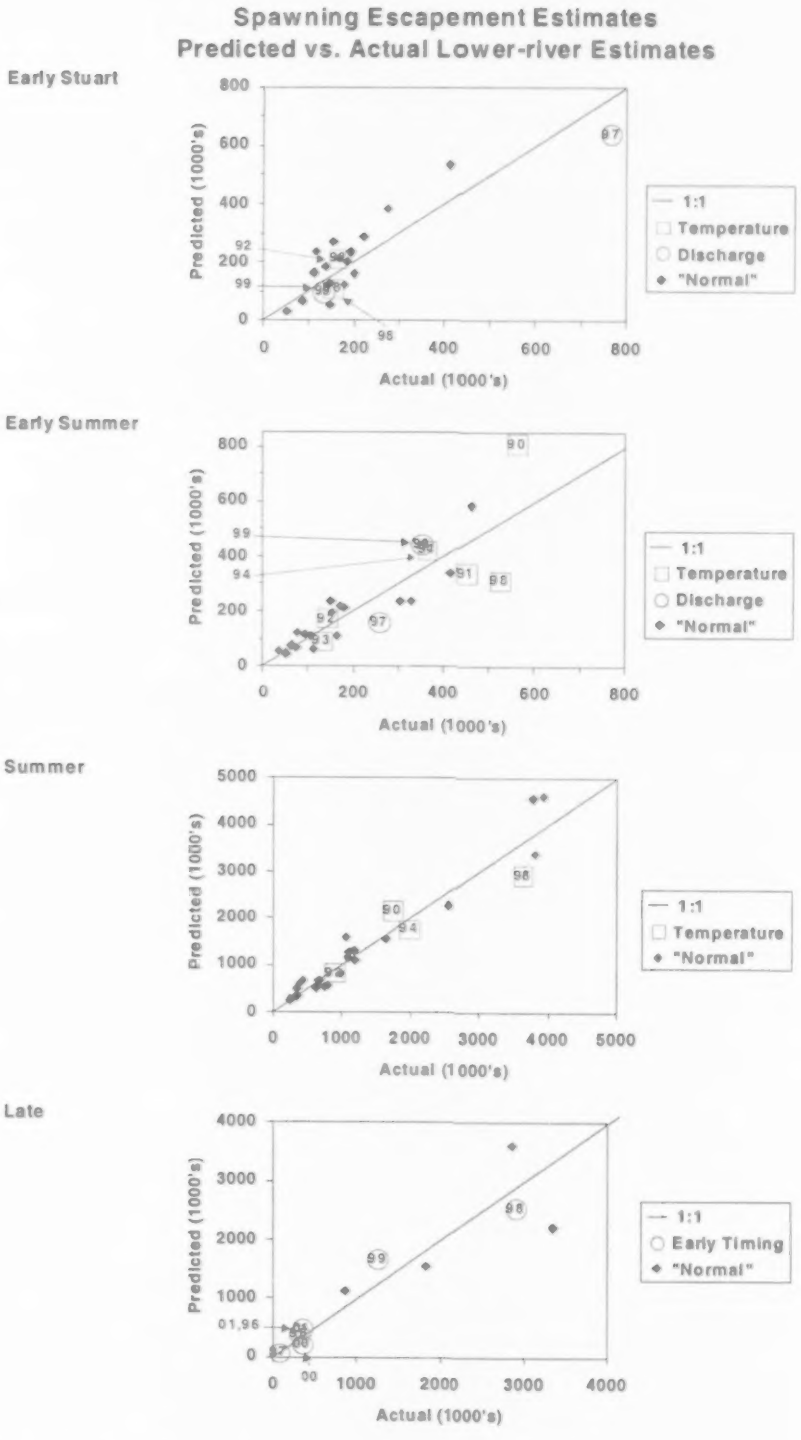

Figure 2. Predicted versus actual lower-river spawning escapement estimates derived from the "best" environmental management adjustment models for each run-timing group (Table 1), showing years of extreme temperature or discharge for early and summer stocks, and 50% migration date at Mission for the Late run.

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Pearce, P.H. 1992. Managing salmon in the Fraser: Report to the Minister of Fisheries and Oceans on the Fraser River salmon investigation with scientific and technical advice from Peter A. Larkin. Canada. Department of Fisheries and Oceans. Vancouver BC. 36p.

The Fraser River Sockeye Public Review Board (Canada). 1995. Fraser River sockeye 1994: Problem and discrepancies. 131p.

FISH-FORESTRY RESEARCH IN SUPPORT OF HABITAT MANAGEMENT

Erland MacIsaac

Forestry affects the largest land-base in the Pacific Region and DFO Habitat Managers in all Areas are challenged with managing land-use impacts from logging on fish and fish habitat. Current concerns regarding forestry practices in BC include the lack of mandatory riparian protection for small fish-bearing and headwater streams and the cumulative effects of logging and road building on watershed functions and fish productivity.

The DFO Fish-Forestry Research Program, in partnership with Provincial and University researchers and First Nations, has conducted research on the natural functions of small streams and their riparian zones and the effects of forest harvesting on small stream processes. Despite the predominance of small stream channels in the drainage networks of most watersheds, relatively little is known about their importance to fish habitat and productivity within watersheds.

Surveys of small streams in the BC interior show that current forest practices significantly impact the riparian zones of small streams (Figure 1). For example, exposure of the streams to direct solar radiation increased two to four times after logging due to reduced canopy cover (Figure 2 and 3). Reduced canopy and increased solar radiation increase stream temperature, expose stream communities to ultraviolet radiation, and alter the foodwebs and species composition of stream communities.

Figure 1. Impacted riparian zone of a small stream.

Figure 2. Stream monitoring. Note extensive forest canopy over the stream.

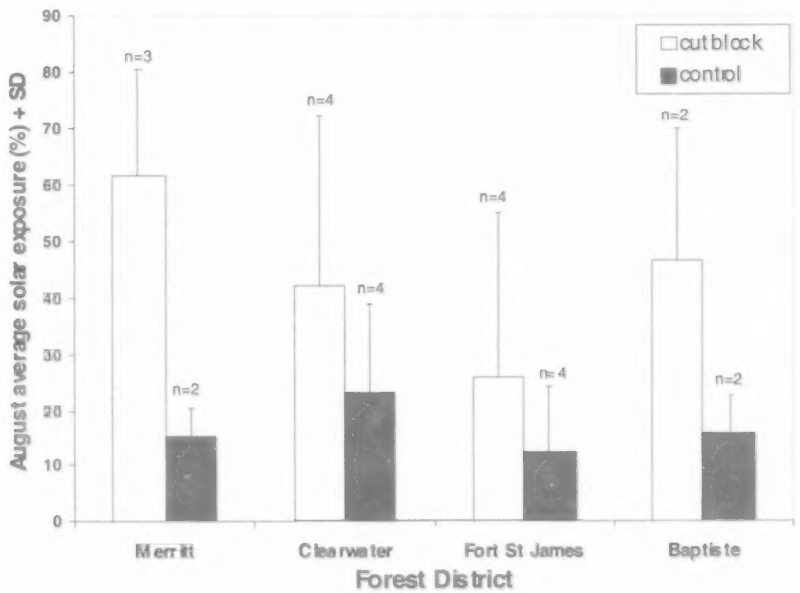

Figure 3. August average solar exposures of streams after logging.

The effectiveness of managed riparian buffers to protect the temperature, water flow, suspended sediment, and macro-invertebrate community attributes of small streams were studied in the Baptiste experimental watershed of the Stuart-Takla Fish-Forestry Interaction Study (Figure 4). Comparisons were made among high and low retention buffers, a patch buffer, and no riparian buffer (with all merchantable timber harvested)(Figure 5).

Figure 4. Baptiste experimental watershed of the Stuart-Takla fish-forestry interaction study.

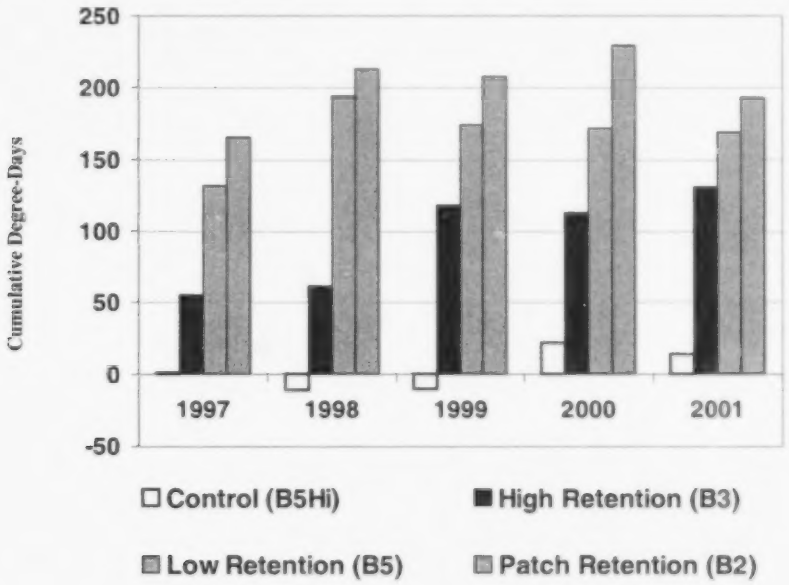

Figure 5. Comparison of stream temperatures found in high and low retention buffers, a patch buffer and no riparian buffer in the Baptiste experimental watershed (1997-2001).

None of the buffers mitigated against temperature increases in the Baptiste streams. Increases in cumulative degree-days over the growing season were highest in the patch cut and the low retention buffer. Increases in the high retention buffer were about half that found in the other buffers. Increases in water yields, peak spring flows, and suspended sediments also occurred, but were largely unrelated to the type of managed riparian buffer applied.

Changes in stream biota in the Baptiste streams reflected reductions in canopy cover and organic matter input into the streams (Figure 6). There were significant declines in invertebrate species that are functional shredders and detritivores (feeding primarily on litterfall) found in the stream with the low retention buffer. The invertebrate community in the stream with the high retention buffer remained similar to that of the control sites.

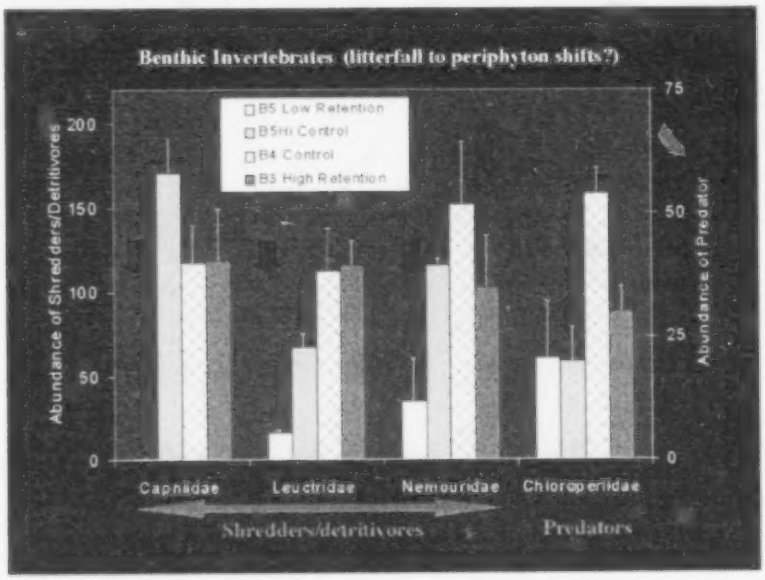

Figure 6. Abundance of benthic invertebrates in Baptiste streams.

Research is continuing in the central interior of BC to improve our understanding of the linkages between downstream fish habitats and their tributary and headwater streams (Figure 7). Small streams may serve as important rearing and refuge areas for juvenile salmonids. Fish in downstream reaches depend on upstream sources for cool water, drifting organic matter and invertebrate food.

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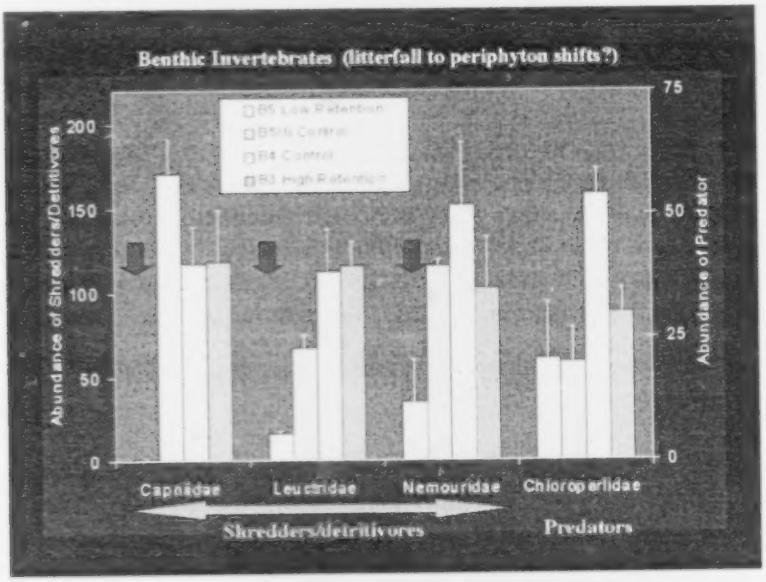

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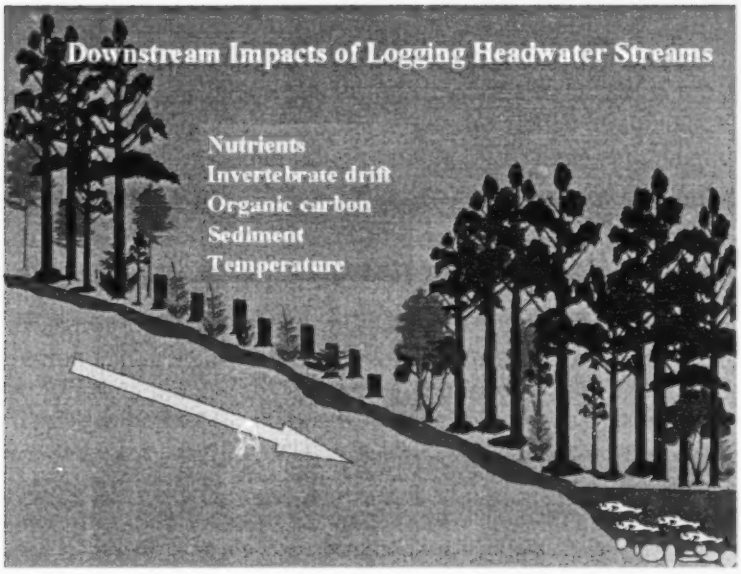
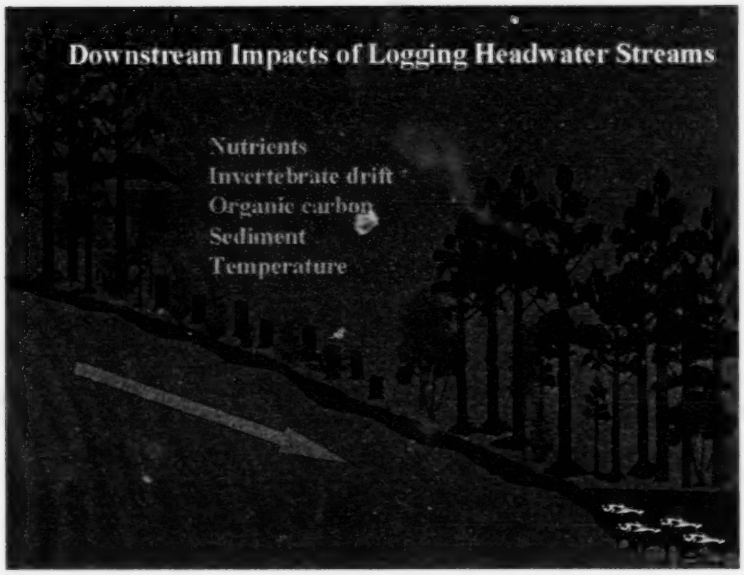


Figure 7. Linkages between downstream fish habitats and their tributary and headwater streams.

Pre-harvest data are being collected from streams in future cutblocks in the Prince George Forest District to quantify the importance of natural upstream sources to stream communities and to determine the effects of forest harvest and riparian removal on stream processes and downstream linkages. Improving our knowledge of small stream and riparian functions is an important part of sustainable forest management and the protection of aquatic and fish habitats.

Forest management in BC is evolving from a prescription-based Forest Practices Code to a performance-based Forest Stewardship Act. DFO Habitat Managers will face new challenges to measure the effectiveness of the forest industry at achieving sustainable riparian and stream management results. New knowledge and science-based decision tools are needed to aid them in assessing forestry impacts on fish and fish habitat.



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LAKES WITHIN LANDSCAPES: VARIATION IN TROPHIC STATUS IN A CHAIN OF THREE LARGE SOCKEYE NURSERY LAKES IN NORTH-CENTRAL BRITISH COLUMBIA.

Ken Morton, Ken Shortreed, and Jeremy Hume

The Lakes Program investigates trophic status of sockeye salmon (*Oncorhynchus nerka*) nursery lakes, to determine rearing capacities for juvenile sockeye salmon and identify factors limiting productivity. An example of the types of research questions we investigate is how landscape position may influence lake trophic levels.

The Stuart lake chain is comprised of three sockeye producing lakes (Takla, Trembleur, and Stuart) within British Columbia's Fraser River system (Figure 1). Offspring of anadromous sockeye salmon rear in these lakes for 1-yr before migrating seaward. Physical, chemical, and biological conditions within the lake environment strongly affect growth and survival of rearing juvenile sockeye salmon. Historically, limnologists studied lakes as spatially independent entities. Only recently has the concept of lakes existing in series along spatial gradients or cascading chains been considered. We analysed limnological data from the Stuart lake chain collected over a 3-yr period (1996-1998) to determine how landscape position influences specific lake variables, lake trophic status, and juvenile sockeye growth (Figure 2).

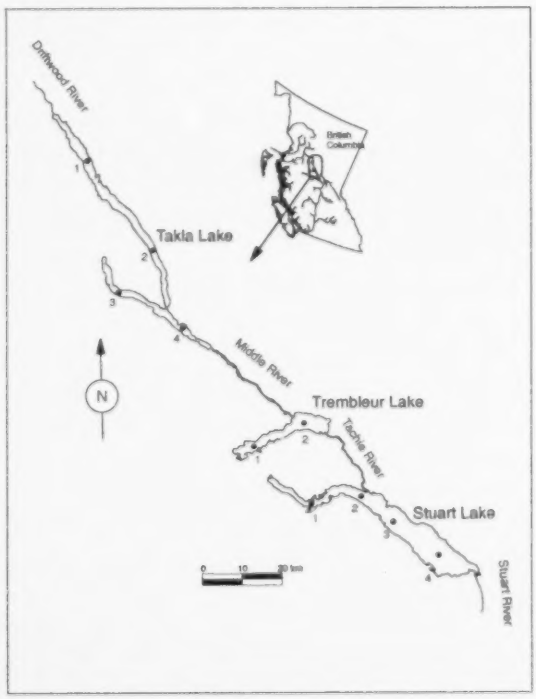

Figure 1. Map of British Columbia's, Stuart Lake System and sampling locations. Takla, Trembleur and Stuart lakes are positioned upstream to downstream in a south-east direction.

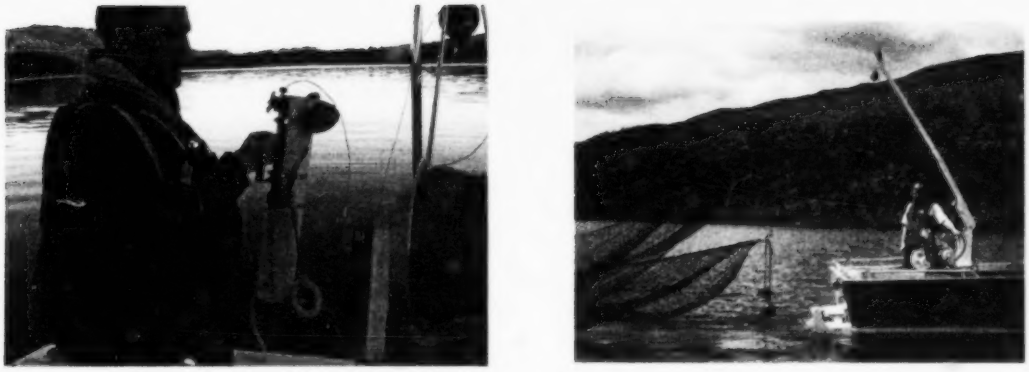

Figure 2. Sampling water chemistry on station (left). Mid-water trawling for a limnetic fish sample (right).

Variables, subject to weather processes such as alkalinity, pH, and total dissolved solids, increased down the lake chain (Figure 3). Total phosphorus at spring overturn also increased with increasing landscape position, but seasonal average epilimnetic nitrate concentration decreased. Chlorophyll concentration and total zooplankton biomass increased down the lake chain (Figure 3), but Daphnia biomass (the preferred prey of juvenile sockeye) and juvenile sockeye growth rates were greatest in Trembleur Lake (middle lake in the series) (Figure 4). The lakes in our study became progressively more productive with increasing landscape position. However, along with increases in zooplankton standing stock a shift came in zooplankton community structure to more predator-resistant forms. This resulted in lower growth rates for juvenile sockeye.

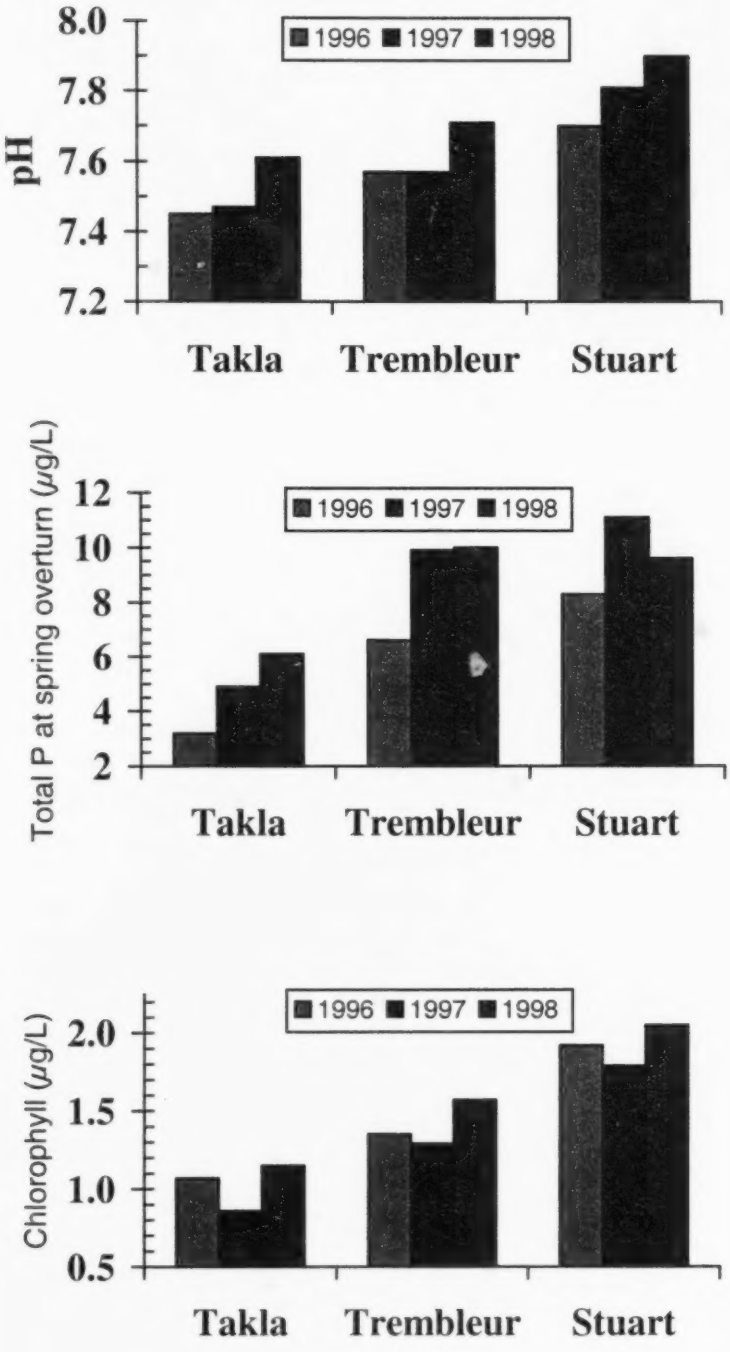

Figure 3. Chemical variables such as pH and total phosphorus increased with increasing landscape position as did chlorophyll concentration.

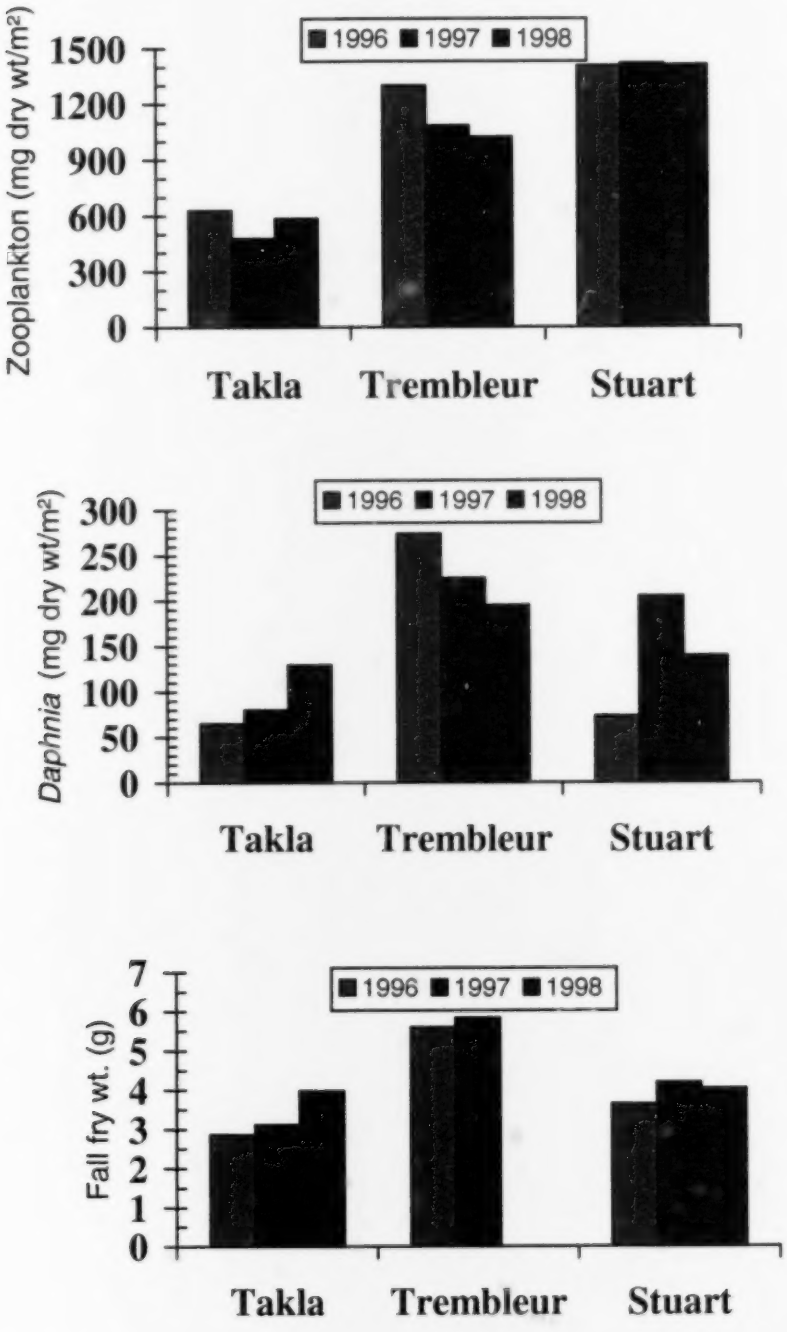

Figure 4. Zooplankton standing stock increased with landscape position; however, there was shift in zooplankton community structure to more predator-resistant forms and fewer Daphnia. This resulted and lower growth rates for juvenile sockeye.

CURRENT LIMNOLOGICAL STATUS OF OWIKENO LAKE

Ken Shortreed and Ken Morton

For most of the past 100 years, Owikeno Lake produced one of the larger runs of sockeye salmon in British Columbia. Although both catch and escapement varied, there were few distinct trends in abundance until the 1990's, when spawner numbers declined to 3,600 in 1999 (Rutherford and Wood 2000). In both 2000 and 2001, spawner numbers increased slightly to approximately 20,000 (Holtby 2002), but were still far below the long-term historical average of 350,000. Possible causes of this decline are varied, but could include changes in the freshwater environment and changes in marine conditions. Freshwater and marine survival indices for Owikeno sockeye indicate that the decline in stock size was attributable to marine and not freshwater conditions (Rutherford *et al.*, 1998; Rutherford and Wood 2000; McKinnell *et al.*, 2001), but there is considerable uncertainty in some of the data used to calculate these indices.

Appropriate limnological data would provide the means to make a direct assessment of the freshwater environment, and to make comparisons between past and present conditions in Owikeno Lake. Limnological studies of varying focus, duration, and intensity were carried out on Owikeno Lake in the 1950's (Foskett 1958), 1960's (Ruggles 1965; Narver 1969), and 1970's (Chernoff 1971; Stockner and Shortreed 1979). However, after the 1970's no limnological studies were carried out, although some types of limnological data were occasionally collected (P. Rankin, DFO, Pacific Biological Station, Nanaimo, BC, unpublished data; E. MacIsaac, DFO, Simon Fraser University, Burnaby, BC, unpublished data; D. Rutherford, DFO, Pacific Biological Station, Nanaimo, BC, unpublished data).

Because of the lack of current limnological data, it was not possible to make direct comparisons of past and present physical, chemical, and biological conditions in the lake. Consequently, in 2001 the Lakes Group of the Freshwater Habitat Science Section was asked to undertake a limnological study of Owikeno Lake. Our investigation had three main objectives: first, to determine the current trophic status and productive capacity of Owikeno Lake; second, to determine if limnological conditions have changed in the last 30-40 years; and third, to assess the potential effectiveness of lake fertilization in accelerating the recovery of Rivers Inlet sockeye salmon.

Owikeno is a large (surface area of 94.5 km^2) lake located on British Columbia's central coast at an elevation of only 15 m. The lake is 56-km long and discharges into the head of Rivers Inlet via the 6-km long Wannock River (Figure 1). It is a fiord-type lake with a mean depth of 172 m. The lake flushes rapidly and has a residence time of only 1.6 yr. The lake is made up of four basins, with the bottom (main) basin comprising 72% of the total surface area. The lake's orientation and location in steep mountainous terrain result in frequent, strong outflow winds, particularly in the main basin.

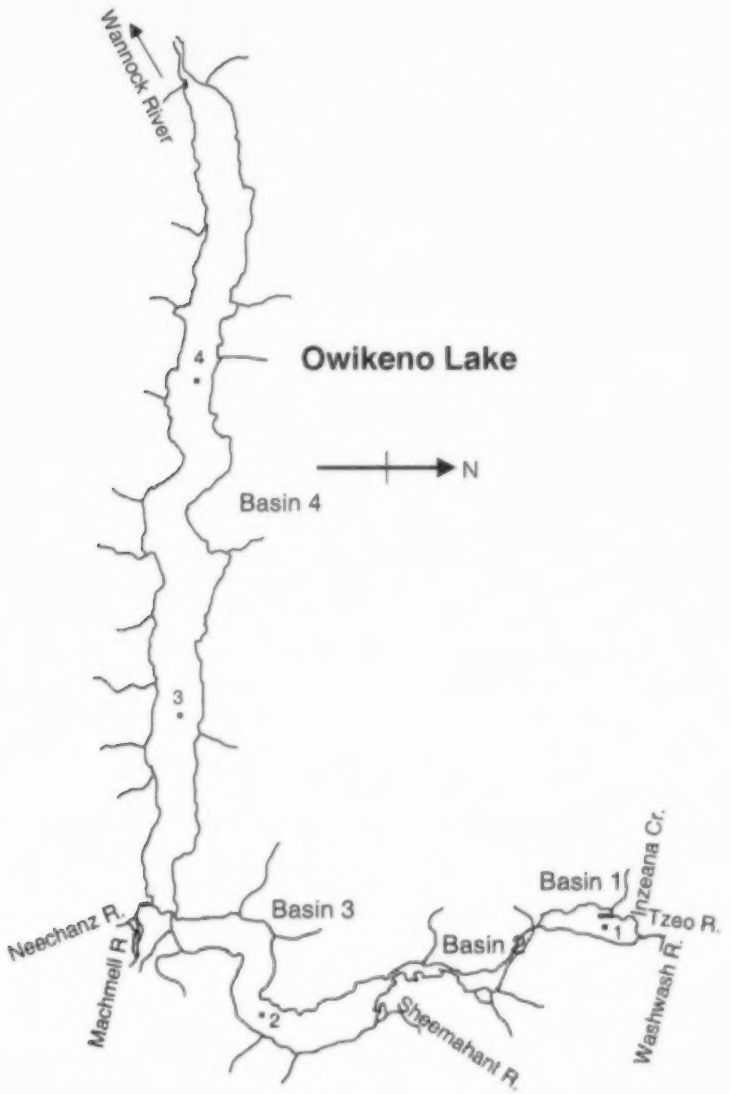

Figure 1. Map of Owikeno Lake with location of the four sampling locations in the 2001 study.

The Lakes Group collected a wide range of physical, chemical, and biological data from four sites in Owikeno Lake once monthly (n=6) from May to October (Figure 1). These data indicated that Owikeno is thermally dynamic, with a cool (mean seasonal temperature of 11.4°C) epilimnion and a relatively weak, unusually deep (average depth of 41 m) thermocline. Because of glacially turbid tributaries entering the two lower lake basins, average euphotic zone depths were only 5.1 m. Spring total phosphorus concentrations (3.4-5.4 μg/L), average chlorophyll concentrations (0.98-1.5 μg/L), average photosynthetic rates (113 mg $C \cdot m^{-2} \cdot d^{-1}$), sestonic C:N:P ratios (168:11:1), and a variety of other limnological variables all indicated that Owikeno Lake is oligotrophic,

but more productive than most other coastal BC sockeye lakes (Figures 2 and 3). A sockeye rearing capacity model (the PR model) modified to factor in the small size of Owikeno smolts predicts the lake currently has the capacity to produce 33 million smolts from a total escapement of 0.6 million, which exceeds most historical escapements. A comparison of limnological data from this study with data collected in various studies from the 1950's to the 1990's did not reveal any changes in freshwater conditions that could be responsible for the recent declines in Owikeno sockeye (Figure 4). After assessing the lake as a candidate for fertilization, we conclude that fertilization might benefit sockeye, but annual costs would be high ($150,000 - 200,000), it would have to be carried out for many years, and the probability of either benefiting sockeye or of detecting those benefits would be lower than in most other sockeye nursery lakes.

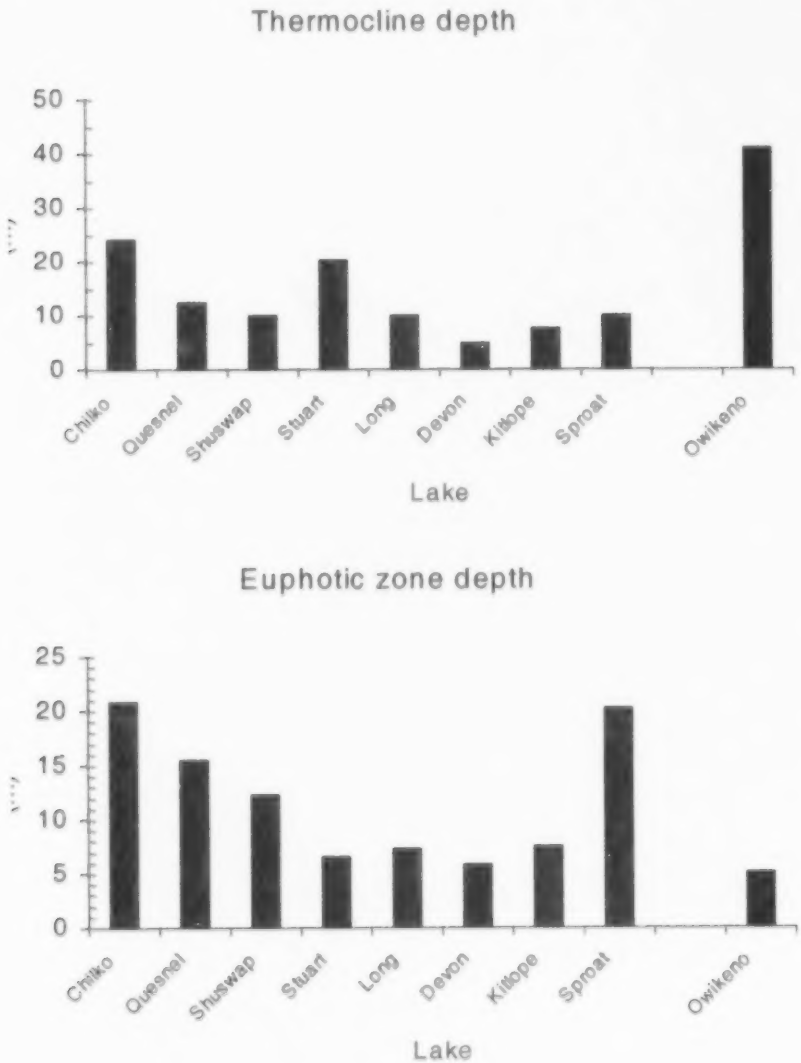

Figure 2. Seasonal average thermocline and euphotic zone depths in Owikeno Lake in 2001. For comparative purposes, seasonal average values from a number of other sockeye nursery lakes are presented.

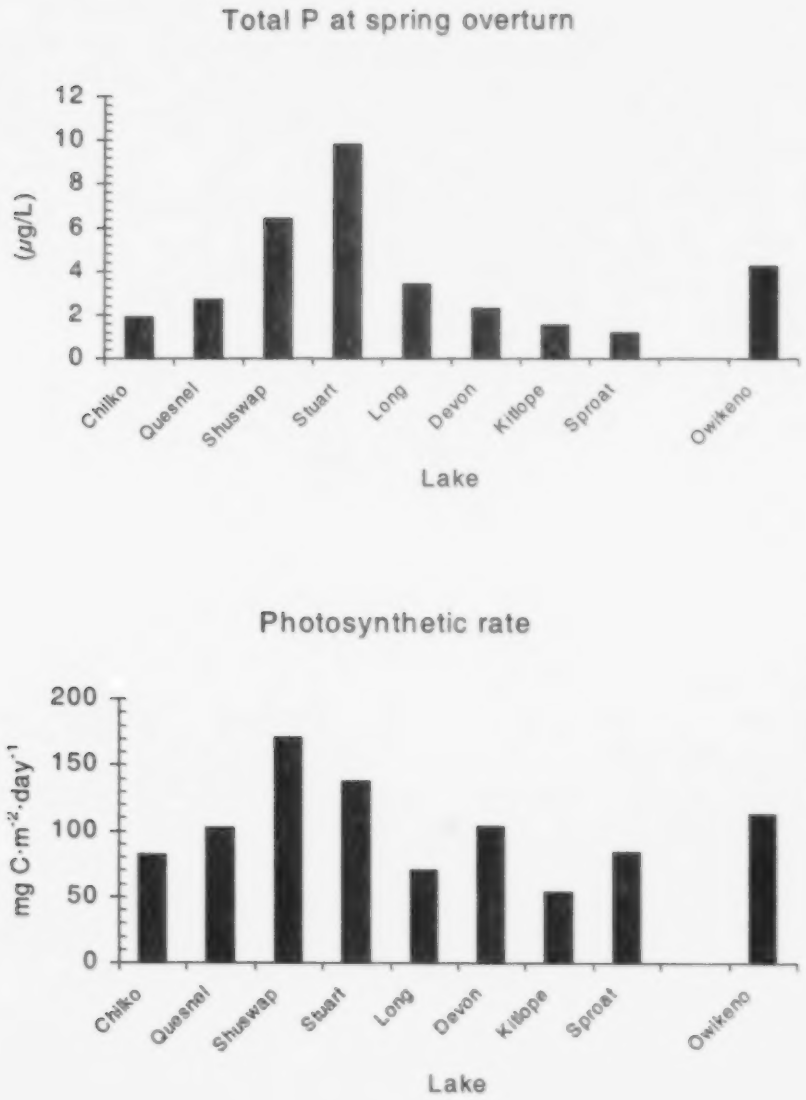

Figure 3. Spring overturn total phosphorus and seasonal average photosynthetic rates in Owikeno Lake in 2001. For comparative purposes, seasonal average values from a number of other sockeye nursery lakes are presented.

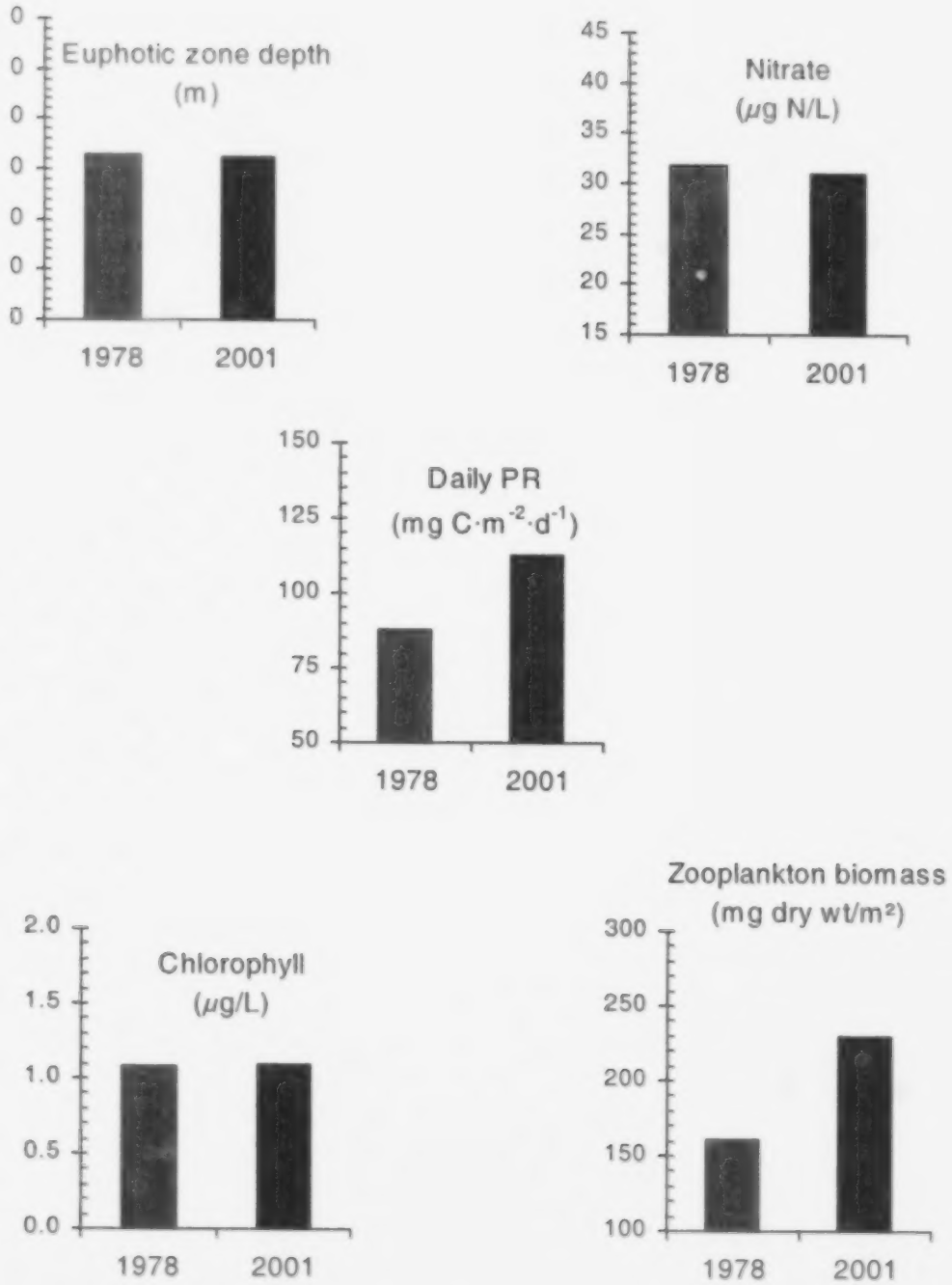

Figure 4. Seasonal averages of selected variables from 1978 and from 2001.

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COASTAL AND MARINE HABITAT SECTION

DISTRIBUTION AND ABUNDANCE OF JUVENILE SALMONIDS IN THE COURTENAY ESTUARY-1998

Beverley Bravender

The Courtenay River estuary is located on the west coast of British Columbia between the cities of Courtenay and Comox on the east coast of Vancouver Island (49° 40′ latitude, 124° 55′ longitude) (Figure 1). In 1997 Fisheries and Oceans Canada began the development of a management plan for an area including the lower Courtenay River and its estuary to the south of Goose Spit and the Trent River delta. During the planned development, it became clear that information was lacking on the distribution, abundance and rearing of juvenile salmon within this area. In May of 1998 a field program was developed to assess the distribution and abundance of juvenile salmonids within the lower river and estuary. Between May 6th and July 29th, 1998, a total of 176 duplicate beach seine sets were completed at 17 sites within this area. Representative samples of salmon of each species were weighed and measured in the field and released. Temperatures and salinities were also recorded.

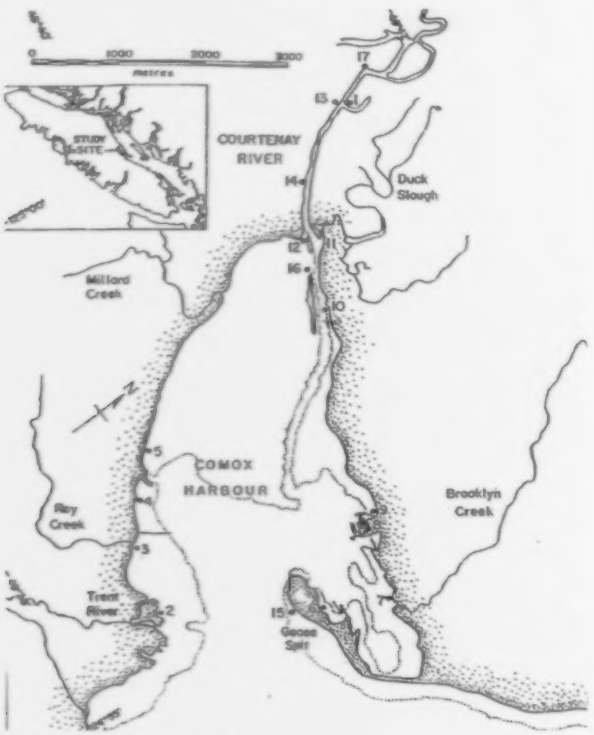

Figure 1. Location of the Comox River estuary.

It was hypothesized that the habitat in the upper estuary offered rearing conditions that were significantly different from the conditions in the lower estuary. ANOVA analysis of the salinity data showed a significant difference for both surface salinities ($P<0.01$) and all salinities ($P<0.01$) between these two zones. Surface temperatures were also significantly different ($P<0.05$) (Figure 2). During four of the six sampling trips, temperatures were significantly higher in the lower region of the estuary when compared to the upper region. As well, the upper region was influenced by the flow from the river to a much greater extent than the lower region. Some of the highest temperatures and salinities were recorded on the broad expanse of shallow mudflats on the north east side of the estuary. Few salmon juveniles were found in this area. Approximately half of the temperatures recorded during the study were between 16° and 20°C, far exceeding the recommended rearing temperature range for juvenile salmonids of 12° to 14°C (Brett 1952).

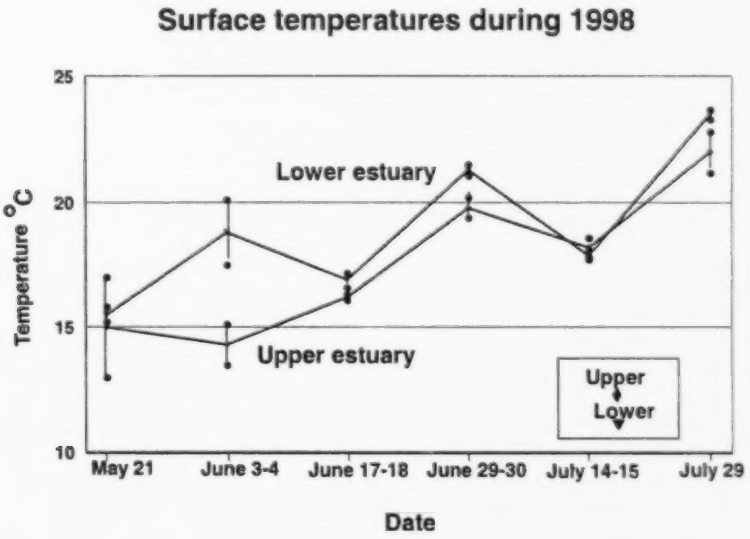

Figure 2. Courtenay River estuary surface water temperatures from May 21st to July 29th, 1998.

Higher capture numbers of both coho fry and chinook fry and smolts often occurred in off-channel habitats, including man made pockets and dredged sloughs which appeared to offer deeper water and some relief from the higher currents found within the main river channel. Suitable habitat for rearing, especially low tide refuges, does not appear to be adequate within the estuary. Despite releases of large numbers of juvenile hatchery salmonids from the Puntledge River Hatchery and the emigration of juveniles from wild spawners in the system, during this project only 734 juvenile salmonids were caught. Chinook dominated the catches in the upper estuary (53.2%) and coho dominated the lower estuary (40.4%) (Figure 3). Juvenile salmon were present in the upper estuary until late June; but occurred in the lower estuary predominately in May. Large numbers of non-salmonid species were caught during the survey, including stickleback, which dominated the upper region and sculpins, which dominated the lower region.

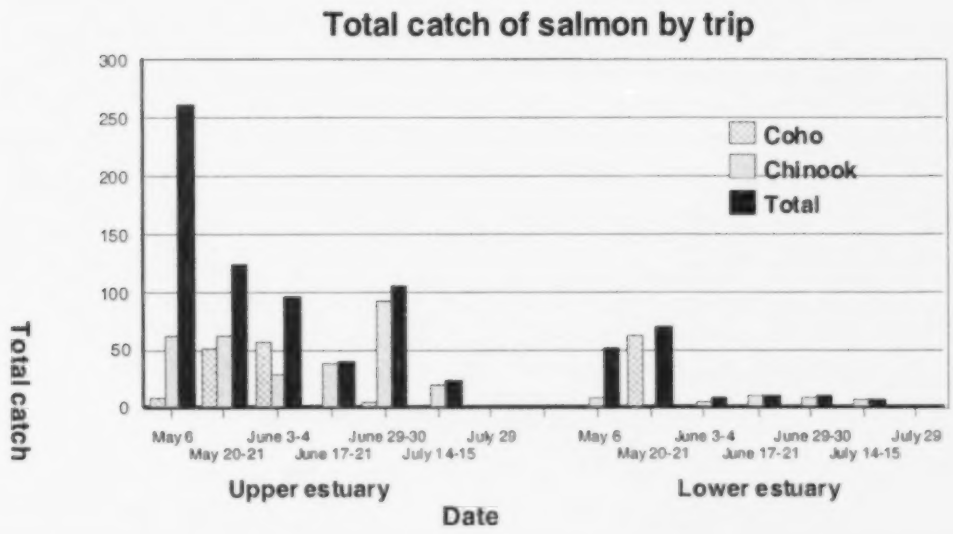

Figure 3. Total salmon catch by trip in both the lower and upper regions of the Comox River estuary between May 6th and July 29th, 1998.

Catches of juvenile salmonids during this project were much lower than expected, especially when compared to other estuaries such as the Campbell River. Further work is required to investigate the results obtained during this study as well as to determine if the juvenile salmonids migrate out of the estuary into Baynes Sound and rear in the surrounding area.

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A COMPREHENSIVE STUDY OF BRITANNIA MINE'S ECOLOGICAL IMPACT TO ASSIST IN RESOLVING AN ACID MINE DRAINAGE PROBLEM

Colin Levings

Background and rationale

The acid mine drainage (AMD) from the abandoned copper mine at Britannia Beach, BC, has been recognized for many years as one of the region's major threats to fish (Figure 1). Several field and numerous lab bioassay studies done by Environment Canada and Province of BC biologists demonstrated the acute toxicity of the AMD, but none of the results were published in the scientific literature and none of the studies had taken an ecosystem (field) approach to the problem. DFO research projects were conducted in the 1970's, however, this project focused on tailings, not AMD. None of the previous work focused on salmonids.

Figure 1. Schematic diagram of the abandoned copper mine at Britannia Beach, Howe Sound, BC. Courtesy of Geological Survey of Canada.

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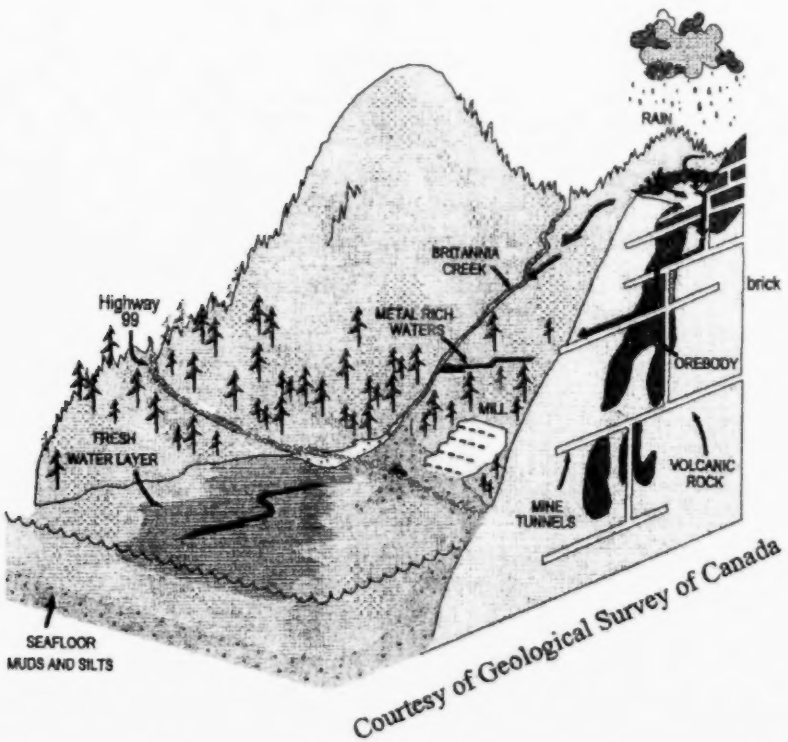


Figure 1. Schematic diagram of the abandoned copper mine at Britannia Beach, Howe Sound, BC. Courtesy of Geological Survey of Canada.

In 1996, the problem was again recognized as a priority by DFO Habitat and Enhancement Branch (HEB) and Environment Canada biologists.

Study Design

The study was organized on an ecosystem/food web basis with field and laboratory projects dealing with: algae (phytoplankton, macroalgae); plankton and epibenthos; and fish (community, population, and individual approaches, with emphasis on chum salmon fry). The project began in April 1997 and ended on March 31st , 2000. Dispersion of dissolved copper and changes in pH were correlated with the biological data on abundance and survival effects observed in the laboratory (Figures 2 to 6). The Furry Creek estuary, approximately five km south of Britannia Beach, was used as a reference site. Innovative methods (e.g. transplant experiments with rockweed) were used. Results clearly demonstrated that almost all taxa were at risk from the AMD.

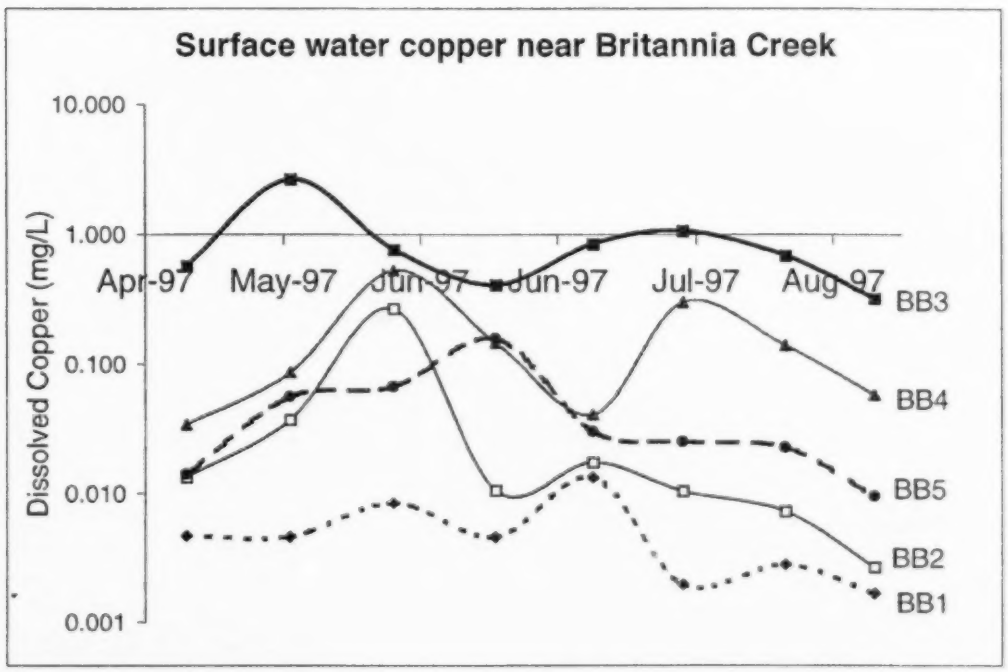


Figure 2. Seasonal change in dissolved copper (mg/l) in surface water collected in 1997 at stations at the mouth of Britannia Creek (BB3, BB4) and stations further to the south and north of the creek mouth (from Barry et al., 2000).

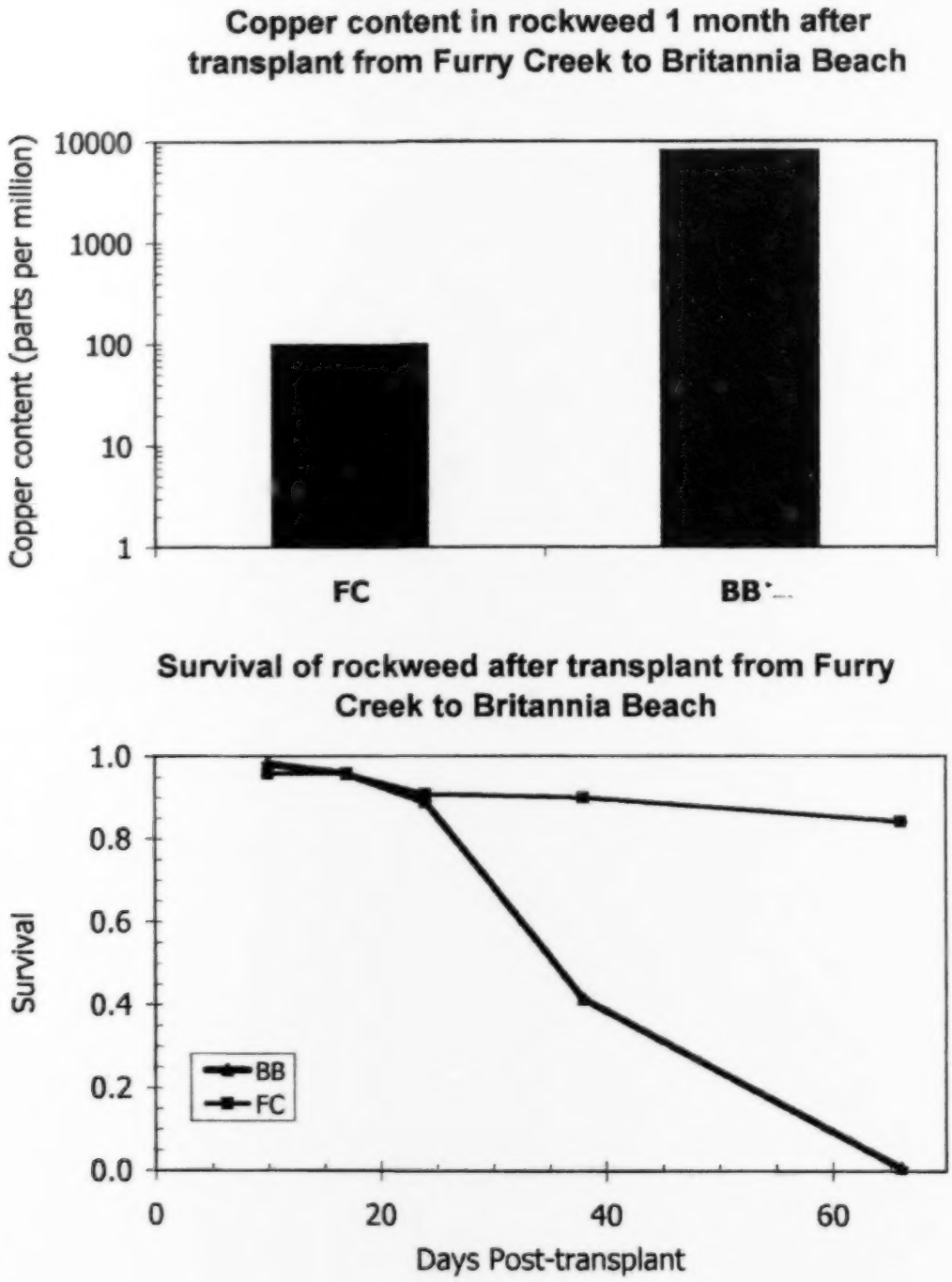


Figure 3. Mortality and copper uptake for rockweed (Fucus gairdneri), transplanted to the mouth of Britannia Creek and the Furry Creek estuary (from Marsden et al., 2003).

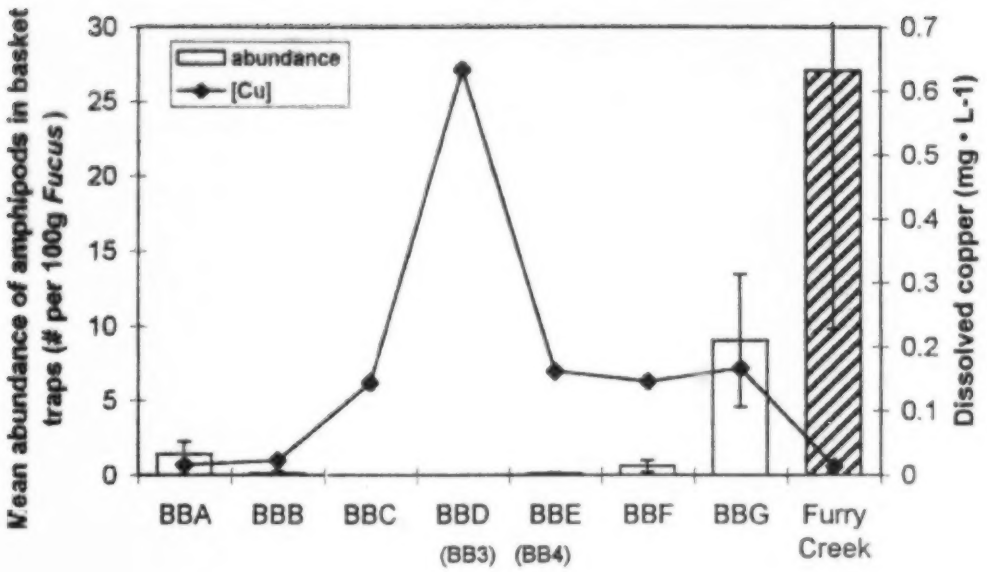


Figure 4. Abundance of amphipods (Eogammarus confervicolus) in basket traps set out at the mouth of Britannia Creek and the Furry Creek estuary (from Levings et al., 2004).

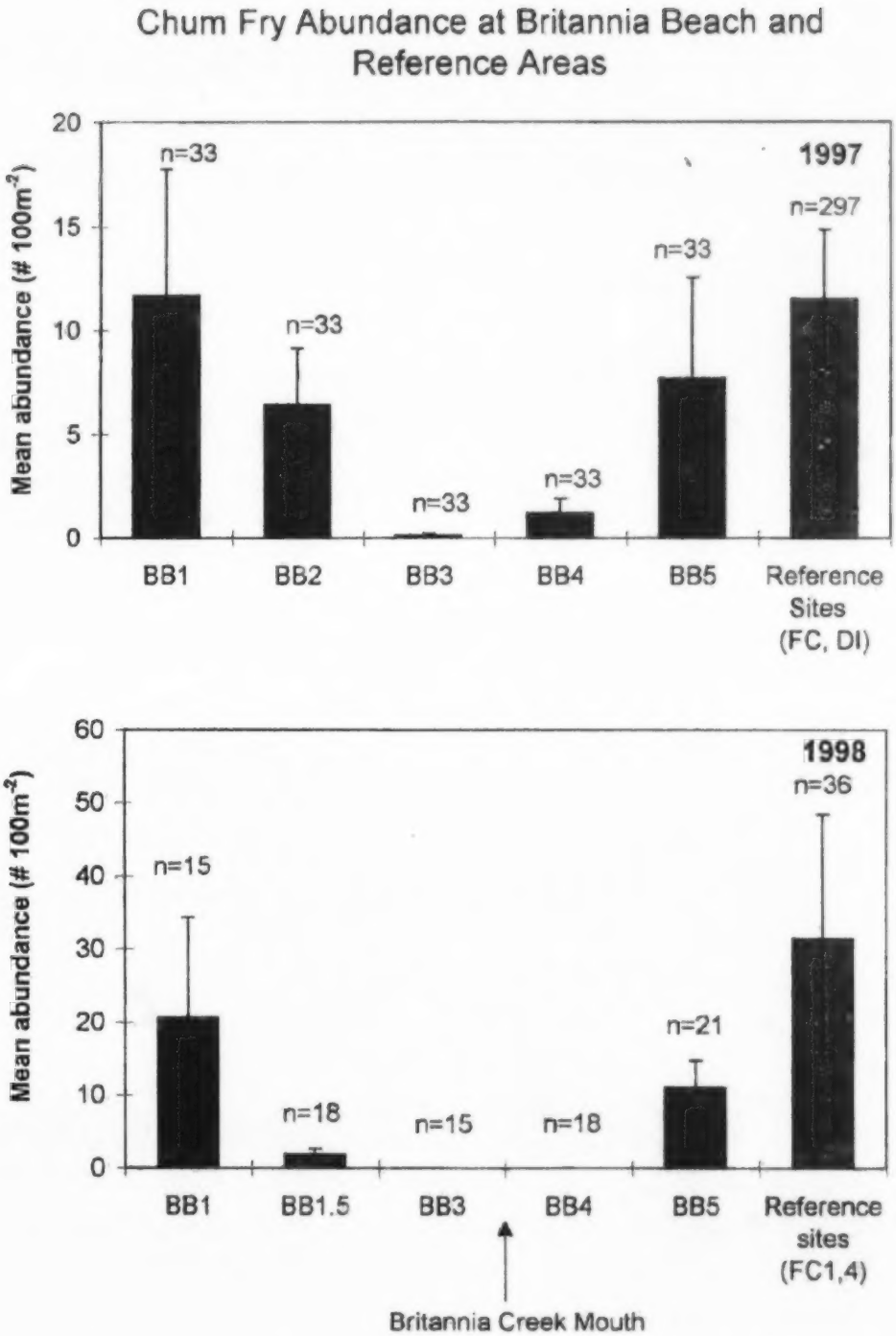
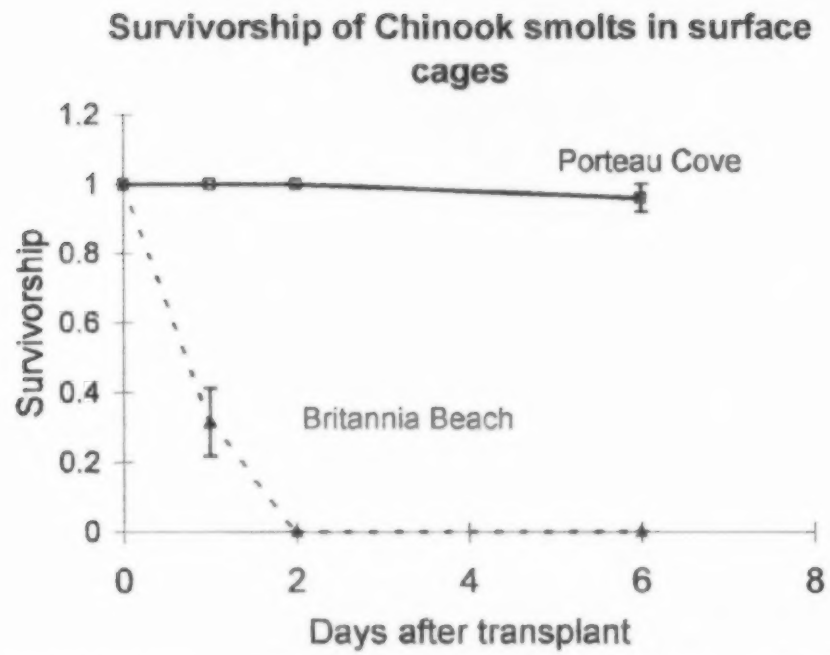


Figure 5. Catches of chum salmon fry (Oncorhynchus keta) at stations at the mouth of Britannia Creek (BB3, BB4), stations further to the south and north of the creek mouth (BB series), and stations similarly arrayed at distances relative to the mouth of Furry Creek. Data shown are seasonal mean values (from Grout et al., 1998 -1999).



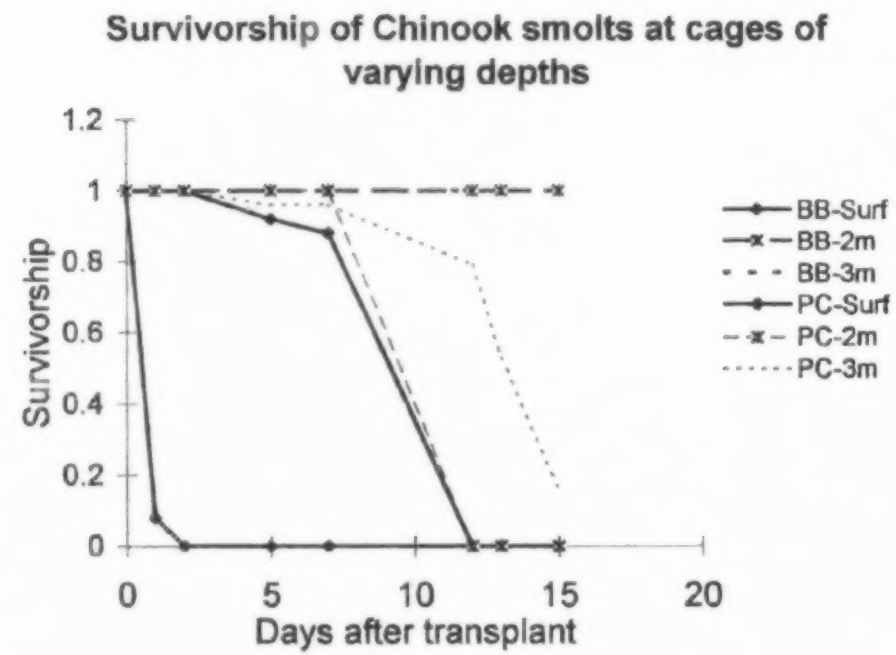


Figure 6. Survival of chinook salmon smolts (Oncorhynchus tshawytscha) in cages held in surface water and varying depths at the mouth of Britannia Creek and Porteau Cove (reference area) (from Barry et al., 2000).

Use of the information and current status of cleanup

The data and publications were successfully used by DFO-HEB in discussions with the Province of BC and Environment Canada to build and operate a treatment plant. Using this money, the BC Ministry of Water, Land, and Air Protection office began studying the remediation of the Britannia mine site. In addition, a private company (Copper Beach Estate Ltd), in association with the Centre for Environmental Research in Minerals, Metals, and Materials at the University of BC, begun work that will eventually divert all of the AMD through a treatment plant. As of December 2001, all the effluent from the mine is now discharged subtidally through an outfall at 30 m depth. Some improvement of the estuarine ecosystem has already been observed, however, further studies are required to confirm recovery.

Acknowledgements

The following were involved in the project: Bruce Nidle, Beth Piercey, Karen Barry, Jeff Grout, Brent Mossop, Andrea Coombs, Nara Mehlenbacher, Terry Maniwa, Steven Shong, and Brian Emmett.

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THE EFFECT OF A BALLAST WATER TREATMENT SYSTEM ON THE SURVIVORSHIP OF MARINE PLANKTON

Terri Sutherland, Colin Levings, Shane Petersen and Wayne Hesse

Two phases of research were carried out in a field and laboratory setting to determine the influence of a ballast water treatment system on the survivorship of marine plankton. An integrated Cyclone-UV Treatment System (ITS) was designed and constructed by Velox Technology Inc. and consisted of two treatment phases: 1) the cyclonic pre-treatment phase, and 2) the ultraviolet radiation phase (UV-C). The first phase of research involved the deployment of a larger-scale ITS (Flow rate: 300 m^3 hr^{-1}) on the Vancouver Port Authority dock, British Columbia. Seawater samples were collected from ports located along the treatment stages of the ITS and analyzed for phytoplankton survivorship through grow-out experiments. Statistical comparisons were carried out on phytoplankton growth parameters, such as, starting concentration, lag phase, growth rate, and relative abundance generated during the incubation experiment. The diatom, *Chaetoceros gracile*, appeared to be the most sensitive to the ITS as it exhibited a 4-day lag phase prior to growth. The starting concentration, growth rate, and relative abundance of this species observed in the UV-treated samples were significantly lower than those observed in the intake samples (control). In addition, the auxospores (reproductive cells) formed by *Skeletonema costatum* (diatom) during the incubation experiment were observed in all treatment samples with the exception of those exposed to the UV stage of the ITS. A second phytoplankton incubation experiment was carried out using the original samples following a 3-month storage period in dark, cold conditions (4°C). The results of this experiment revealed that the phytoplankton populations in the UV-treated samples were not capable of growth, while those in the remaining treatments exhibited growth. Thus, future studies assessing the effect of the ITS on phytoplankton survivorship should incorporate increases in the intensity and exposure period of ultraviolet radiation followed by a dark, cold storage period, thereby reducing the chance of photo repair.

The second phase of research was carried out at the West Vancouver Laboratory to determine the effect of a smaller-scale Integrated Treatment System (Flow rate: 300 m^3 day^{-1}) on the mortality of zooplankton. Various zooplankton species were exposed to the treatment system over a range of 6 ultraviolet dosages (UV-C). In general, both treatment phases (cyclonic pre-treatment and UV-treatment) exhibited significant effects on zooplankton mortality. The results revealed that clam, mussel, and oyster larvae had statistically similar mortality thresholds ranging between 96 % and 99 % at the higher UV dosages. A significant difference was observed when comparing these results to the mortality thresholds of brine shrimp nauplii (77 %) and a natural population of zooplankton (40 %). These findings suggest that species grouped into similar taxa may exhibit similar mortality responses to ultraviolet radiation, while those taxa containing different structural tissues capable of different photo protective properties may exhibit different mortality responses. In addition, time-dependent, post-treatment mortality observations varied according to the taxa present, demonstrating that biological assays

should include time-dependent mortality estimates to accurately assess the efficiencies of ballast water treatment systems.

Acknowledgements

This project was funded through an Alberta Industrial Research Assistance Program, Velox Technology Inc. and Fisheries and Oceans Canada.

NEAR FIELD IMPACTS AND RECOVERY OF SENSITIVE HABITATS UNDERLYING FISH FARMS

Project Team Members: Terri Sutherland, Colin Levings (MEHSD); Rob Hare, Jim Galloway (Canadian Hydrographics Service); Barry Hargrave (Marine Environmental Sciences Division, Maritimes Region); Wayne Knapp (Habitat and Enhancement Branch); and Dario Stucchi (Ocean Science and Productivity)

The objectives of this project were to: 1) determine the zone of influence underlying fish farms in relation to benthic communities, 2) assess proposed monitoring methods designed to detect organic enrichment and classify the level of impact, and 3) determine the recovery or fallowing period of impacted sediments underlying a fish farm. In general, abandoned fish farm sites have been surveyed over time to determine recovery rates of underlying sensitive habitats as certain farms in BC go through a relocation process. Cost-effective monitoring tools, sulphides/Eh, (redox potential) recommended by Maritime scientists have been incorporated into this study in order to assess their ability to detect a HADD (Habitat, Alteration, Disruption, and Destruction) within Pacific Region ecosystems.

Two types of acoustic surveys have been carried out within the vicinity of an abandoned farm site in the Broughton Archipelago, which is located in the south central coast of British Columbia. Bathymetry and backscatter information were acquired from a multibeam EM3000 survey, while substrate habitat classifications were acquired from a QTC View survey. An overlay of the two mapping surveys shows a strong relationship between the reflectivity (backscatter) results and the QTC classifications. The backscatter information was correlated with sediment grain size and semi-trace metal content for ground-truthing and predictive purposes.

Grab samples were collected at reference sites and across the lease area at each abandoned farm site and are currently being analyzed for a variety of geotechnical parameters (grain size, porosity, sulphide/Eh, oxygen, carbon/nitrogen, semi-trace metals) as well as biological properties (macro- and meio-faunal diversity). A modified suction core was developed and used to collect intact vertical profiles of sulphide and Eh measurements of sediment cores. These geochemical parameters have been recommended by Maritime Region scientists as cost-effective monitoring tools for classifying aquaculture impacts (Wildish *et al.*, 1999). The development of a remote coring device compatible with a deep-water environment (Pacific Region) was necessary to allow for direct comparisons of sulphide/Eh measurements collected by scuba in a shallow region (Maritime Region). In addition, an assessment of the variation in background sulphide levels observed within the Pacific Region is taking place to determine if aquaculture impacts can be detected within the outlined sulphide impact classification levels (< 300 μM/Oxic a; 300 – 1300 μM/Oxic b; 1300 – 6000 μM/Hypoxic; > 6000 μM/Anoxic; Wildish *et al.*, 1999).

Spatial and temporal analyses of the geo-technical were carried out in collaboration with UBC (Mehlenbacher 2003). Upon completion of the macro- and meio-fauna analyses, spatial and temporal changes in faunal diversity will be associated with observed changes in the geotechnical parameters in support of HADD determinations. Preliminary results reveal strong inverse relationships between faunal taxa groups and sediment organic carbon and semi-trace metal content. Laboratory experiments are currently being carried out to determine sulphide tolerances of various organisms. This information can potentially be used to identify if a potential HADD could occur based on *in situ* sulphide measurements.

Current meter deployments and CTD casts have been carried out to determine the circulation and physical/chemical properties of the water column within the vicinity of the farm site. This information can be used to explain the depositional characteristics of farm-derived material (verify impact footprint) and also to determine the contribution of bottom currents to the recovery process of impacted sediments. The integration of the physical and biological data collected will allow scientists to predict fallowing processes at future fish farm sites. These findings will allow habitat managers to recommend potential rotational policies for fish farm operations for integrated management purposes to ensure the long-term success of the aquaculture industry.

Acknowledgements

This project was funded through the Environmental Science Strategic Research Funds program. We would like to thank Shane Petersen, Beth Piercey, Mike McDermid, Nara Mehlenbacher, Scott Morrison, and Perry Poon for their assistance in the field sampling and laboratory analyses.

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ENVIRONMENTAL STUDIES FOR SUSTAINABLE AQUACULTURE

Project Leaders: Barry Hargrave (Leader Maritimes Region); Robin Anderson (Leader Newfoundland Region); Terri Sutherland and Colin Levings (Co-Leaders, Pacific Region).

Pacific Region Project Team Members: Terri Sutherland, Colin Levings (MEHSD); Fern Hietkamp (Oceans); Dave Higgs (Aquaculture); Wayne Knapp (HEB); Dario Stucchi (OSAP)

This project focuses on the potential cumulative and far-field impacts of aquaculture operations through broad-scale surveys across different coastal morphologies found in Canada: Bay d'Espoir, NF (a steep-sided fjord), Passamaquoddy Bay/L'Etang Inlet, NB (a macrotidal estuary) and Broughton Archipelago, BC (a coastal island group). The research will answer the following questions:

1) How can assimilative capacity in coastal waters be determined for particulate and dissolved waste produced by finfish aquaculture?
2) What measurements can be made to document changing patterns and rates of sedimentation?
3) How can dissolved particulate material released from aquaculture sites be tracked within a coastal system? And
4) How are these environmental objectives to be used by habitat managers to ensure that a HADD (Harmful Alteration, Disruption or Destruction) will not occur at existing or new aquaculture operation sites?

Research carried out in the Pacific Region has focused on benthic impacts and transport pathways of water-born, farm-derived particulates. Benthic community structure, sedimentation fluxes, and circulation patterns surrounding various fish farm sites within the Broughton Archipelago (southcentral coast of BC) have been determined. Isotope and semi-trace metal analyses were carried out on sediment and sediment trap material to determine a cost-effective tracer of waste feed and faecal material.

Stations were located at 0 m, 30 m, and 300 m along two transects in the dominant upstream and downstream directions at each farm site. Additional reference stations were located approximately 500 to 1,000 meters from each farm site. Six far-field stations were positioned along a passage located between the farm sites. Van-Veen grab and core samples were collected in order to determine the extent of potential benthic impacts within depositional fields. The grab samples were processed for both macro-and meiofaunal analysis. Core samples were analyzed for oxygen, Eh (redox potential), sulphide, and carbon/nitrogen content. However, due to the coarse nature of the seafloor and logistical problems that occurred, the number of core and grab samples collected was limited. Preliminary results reveal a strong inverse relationship between meiofauna taxa and sediment sulphide concentration. In addition, benthic chambers were deployed in the

far-field region (300 m from farm site) to determine the respiration rate of the benthic environment. Five replicate grab samples were collected at the chamber stations to typify the fauna responsible for the observed respiration rates.

Sediment traps were also set along the station transects in the dominant upstream and downstream current directions. The sediment traps aid in collecting information regarding the dispersal characteristics of water-borne waste particulates. The material collected will then be analyzed for total suspended solids, chlorophyll, and carbon/nitrogen content. Isotope analysis and a metal scan will also be conducted to determine a potential tracer of waste particulates. A tracer of feed pellets and faeces is required in order to determine cumulative far-field effects of aquaculture waste.

Current meters were deployed for one month (to capture a full neap/spring cycle), at a distance of 300 metres from each farm site in the dominant upstream and downstream current directions. Time-series of water property profiles were carried out in the downstream direction at each site to determine the circulation and physical/chemical properties of the water column. Additional water column profiles were collected in surrounding channels to determine background measurements of water column properties. Models of circulation are currently being developed to predict the transport pathways of waste particulates in order to help validate the existing regional siting criteria.

Acknowledgements

This project was funded through the Environmental Strategic Science Research Funds Program. We would like to thank Shane Petersen, Beth Piercey, Mike McDermid, Nara Mehlenbacher, Scott Morrison, and Perry Poon for their assistance in the field sampling and laboratory analyses.

ECOLOGICAL ASSESSMENT OF INSHORE TRAWLING AND TRAPPING ON BENTHIC HABITATS IN THE PACIFIC REGION

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The use of mobile fishing gear has become a growing concern due to recent recognition that trawling can have a significant effect on biological diversity and community structure in benthic habitats (Watling and Norse 1999; Prena *et al.*, 1999). Trawling gear may potentially crush, bury, or expose organisms that live in association with the seafloor altering ecosystem biodiversity. The purpose of this study is to evaluate and weigh the disturbance factor and catch efficiencies of trawling (otter trawl, beam trawl) and alternate fishing methods (trapping) to provide advice to fishery, ocean, and habitat managers.

Field research commenced in July 2000, with a preliminary investigation of trawling effects on sedimentary habitats and benthic communities in Northumberland Channel located near Nanaimo. The work included the development of methods to assess anatomical damage to shrimp caught by beam and otter trawl as well as a detailed documentation of invertebrate and fish bycatch. In collaboration with Canadian Hydrographic Service (CHS), feasibility studies using multibeam echo sounding and substrate mapping were also conducted before and after trawling/trapping activity.

Since collateral damage on the ecosystem has been identified as an issue in a developing fishery for humpback shrimp (*Pandalus hypsinotus*) in the Region, this species and its habitat was selected for detailed work. A comprehensive ecological field experiment was designed for Simoom Sound located on the Central Coast where humpback shrimp are abundant. In August 2000, CHS carried out a baseline survey of the seafloor of Simoom Sound using multibeam and QTCView methods (acoustic technologies). Two non-overlapping "blocks" of benthic habitats approximately 0.5 km long and 60 to 70 m deep were chosen for this long-term study. One block contained 3 replicate trawl lines, while the other block contained 3 replicate trap lines. Ecological data were collected in November 2000, as part of a long-term study. Data in these two blocks were obtained before and after otter trawling and trapping, with specific biological observations on humpback shrimp and bycatch organisms. Pink shrimp (*P. borealis*) dominated the trawl catch, while humpback shrimp dominated trap catches. Humpback shrimp and shrimp bycatch organisms were collected for laboratory studies to assess anatomical damage.

Damage to humpback shrimp was assessed and categorized according to four major regions of the shrimp body (rostrum, carapace, abdomen, and tailfin). Statistical analyses are currently being carried out on this data set.

A camera and optical backscatter sensor were towed approximately 1 m above the seafloor along the individual trawl and trap lines before and after fishing activity to assess potential physical alteration to the seafloor and ambient suspended particulate concentrations. In addition, the camera and optical backscatter sensor were towed approximately 150 m behind the fishing boat during each trawl event. Preliminary observations from Simoon Sound indicated that a sediment plume occurs during trawling activity. An increase in roughness in the seafloor was occasionally observed along the length of the trawl lines as well as the occurrence of "trenches" assumed to be created by door impacts. The seafloor along the trap lines appeared to be less disturbed. Samples were obtained on infaunal and meiobenthic organisms as were samples for sediment properties including grain size, organic content, and pigments. Data reports are currently being generated regarding benthic communities surveyed by grabbing and video methods.

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APPENDIX 1

MARINE ENVIRONMENT AND HABITAT RESEARCH: A NORTH COAST PERSPECTIVE ON NEEDS IN THE NEXT FIVE YEARS

Bruce Shepherd, North Coast Area Chief, Habitat & Enhancement

While the original drivers of the northern economy – the forestry, fishery and mining sectors - are currently in the doldrums, it does not seem to have resulted in any lessening of the habitat workload. And indeed, economic desperation has led many northerners to want to see almost any development at any cost. Forestry is likely to be in but a temporary lull; the incoming Results-Based Code is anticipated to heighten existing habitat challenges with regard to issues such as riparian protection for S4-S6 streams.

In addition, there are some new industries now poised to enter the North Coast arena. To list the major possibilities:

- Offshore Oil & Gas Exploration and Development;
- Aquaculture;
- Electrical Energy Production (marine wind farms, tidal generators, IPP);
- Ecotourism; and
- Cruise Ships.

These new activities are already starting to challenge our habitat practitioners with some unfamiliar and unique questions with regard to potential environmental impacts. Some of the difficult questions that researchers possibly could assist with include:

- What are the impacts of O&G seismic surveys (especially cumulative effects) – development of BMPs, marine work windows, etc?
- What are the risks of disease transfer and HADDs for aquaculture operations? Can diseases/parasites be transferred via non-salmonid and threatened northern species (eg, eulachon)?
- What are rare, critical and sensitive habitats for northern deepwater marine species
- What are the risks of nearshore ballast water exchange with regard to the establishment of introduced exotic nuisance species in northern ports?
- Are riparian buffers always required in the marine environment and in lakes? What is the minimum width for proper functioning?
- How long does it take for stream benthic fauna to recover after disturbance by machinery?
- How long will it take eelgrass and sedge habitats to recover from machine damage?

- What are the habitat needs of the approximately 26 northern species/stocks classified as endangered, and likely to require recovery plans under SARA? And,
- How do we validly incorporate and use First Nations TEK (Traditional Ecological Knowledge) along with scientific data?

Some interesting partnership opportunities are developing in the North (for example, the UNBC Northern Land Use Institute has been given $2,000,000 by the provincial government for a Northern Coastal Information and Research Program, to be spent by the end of this fiscal). Capacity for cooperative research appears to be building rapidly at northern institutions such as UNBC and NWCC, and with local groups such as the Prince Rupert Community Fisheries Development Corporation.

However, all the scientific data in the world is useless to our problem-solving and decision-making if it cannot be easily accessed in a timely manner. To illustrate, shortly after I arrived in Prince Rupert, one of my greatest nightmares materialized. At about 4:00 PM on the Friday of the start of a long weekend, a vessel went aground in the Queen Charlottes and began to spill fuel. Luckily, the spill was minor, but what if it had been a tanker and a major spill?

At the moment, the habitat practitioner's access to data is quite limited, and hampered considerably by various proprietary concerns as well as just plain poor communications. My vision for the handling of a future spill would the following: Upon being advised of a spill, I could plug in its location to a spill trajectory model that automatically adds current tide, weather and sea state conditions; Using that trajectory prediction, I could then forecast the likely landfall of the slick; and I could then access a foreshore database that would allow me to make a virtual video tour of the shoreline involved , and download all available physical, biological and fishery data for that area of both trajectory path and landfall areas. Now, all I have to do is either decide what key sections of the shoreline to protect, or whether to set the slick on fire, use dispersants, or…? The decisions would still be difficult, but at least they would be informed ones.

A pipedream? Perhaps, and it certainly will remain so under the current regime of duplicated databases and competing collection efforts, of inter-agency reluctances to share their databases in a timely manner (eg, the provincial coastal shoreline video library), and confidentiality concerns (eg, the proprietary nature of fishery harvest data). Attention desperately needs to be put to finding ways to make even the existing data usable and accessible by Habitat practitioners.